Modelling the inner-European trade volumes of natural gas

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Abstract

This paper presents a subscripted model of the European gas market that aims on replicating the inner European gas flows. It succeeds in generating some of the reference modes but fails to reproduce the whole system. The model is analyzed and found consequential. The model is then used to analyze three scenarios:

1. The omission of long term contracts
2. The increase of LNG capacities
3. The implementation of bi-directional pipeline flows

The model is used to show the possible trends in the given scenarios. It was found that the omission of long term contracts lead to a need of more gas. Increased LNG capacities lead to more competition and the implementation of bi-directional flows increases the system's flexibility.

Introduction

Taken the tremendous importance of natural gas as an energy commodity and the major changes towards liberalization within the European Union's (EU) gas market, it becomes apparent that the future of the EU gas market structure is not only interesting to analyze for researcher but also for practitioners and political decision makers since there are different key aspects to be considered. First, the security of supply needs to be guaranteed. Second, bottlenecks and malfunctioning of the market mechanisms need to be identified and prevented. Third, the development of the prices for industrial as well as residential customers needs to be predicted. Last, legal changes unbundled incumbent companies and opened the markets for new entrants and new business models of existent companies. These key aspects were regarded in the policies launched within the liberalization process. However, after more than a decade of measures towards liberalization, the impacts hoped for cannot be observed yet (EU, 2011). The role of policy analysis and simulations became important. In this context, several models emerged in order to infer trends and impacts of policies on certain aspects of the above mentioned key aspects. Within the rich literature of natural gas market models, system dynamics have played a minor role.

The aim of this article is to contribute to the existing literature on natural gas market model by providing a basic simulation model structure in system dynamics. This structure may play an important role for further extensions in order to analyze different policies.

We find that a system dynamics model based on three variables (price, availability and trade relations) is of good quality to describe the intra-European trade volumes. However, not all countries natural gas trade activities are correctly represented. Thus, several factors might be missing. Nevertheless, we find that the model can analyze some discussed scenarios: (1) the omission of long-term contracts (LTC), (2) the increase of liquefied natural gas (LNG) capacities and (3) the establishment of bi-directional natural gas pipelines.

Firstly, it has long been debated whether or not LTC are a barrier of entry (EU, 2003/55/EC) and studies show that the very nature of those contracts is changing (Neumann & von Hirschhausen, 2004). Therefore, we analyze which impact has an omission of LTC on the inner European trade in the new framework of the third gas directive and the current market situation. In the scenario of the omission of LTC, the model reveals the lack of capacity and the need for higher production. Secondly, the scenario concerning LNG use derives from actual prediction of LNG growth because of the technological advancements and also to satisfy the need of supply security (Reymond, 2007; Kumar, Kwon, Choi, Cho, Lim, & Moon, 2011). We examine to what extent the inner European trade will change due to the new way of supply. This scenario shows that more gas will come to Europe which will lead to more trade and that the traditional gas flow direction from east to west is not apparent in the scenario. Lastly, the bi-directional gas pipeline scenario focuses on a lately often discussed topic. The EU identified the transmission capacities of inner European pipelines to be a bottleneck in regard to at least two key aspects (EU, 2010): security of supply and inner European downstream competition. In the context of this finding, the idea of a change from one-directional to bi-directional gas pipelines is discussed (EU, 2011a). This paper is one of the first to examine the impact of that change on the current market situation. This last scenario shows that the flexibility of the gas network will increase due to the increased capacities.

In the second section of this article, we give a brief overview about the existing gas market models and their use. In the third second section we present an alternative elementary model which is based upon only three trade indicators – price, availability and trade relation. We find that the basic model already reproduces some of the reference modes analyzed.

Existing Models

Within the process of the EU gas market liberalization, several changes occurred. Those included a forced market opening, guarantee third party access (TPA), legal unbundling of transmission system operators (TSO), distribution system operators (DSO), storage system operators (SSO) and LNG terminal operators from vertical integrated companies and customer switching was simplified (EU, 98/30/EC; EU, 2003/55/EC; EU, 2004/67/EC).

These changes lead to the creation of several predictive models. Most of them had the purpose to forecast prices under different scenarios. In the following the most important and influential models[1] are presented and summarized in table 1. It will give the reader an overview and explains why a new model needs to be created in order to examine the three scenarios focused on in this article.

One of the first models was the EUGAS model developed by Perner and Seeliger (2004). The model emerged under the premise of intensive growth of demand and therefore focuses on the supply. It examines which countries will be main suppliers. Further, it analyses how long the EU can indigenously produce natural gas and how it will be transported with regard to bottlenecks in pipelines. It focuses therefore on security of supply rather

[1] according to google citations

than on the internal market. Under the assumptions of perfect information and perfect competition, the gas price is minimized in order to maximize total social welfare. The simulation results show that the EU will get more import dependent but that there is enough natural gas. The authors conclude that a diversification is needed in order to secure supply. Moreover, enormous investments are needed in technology, production and transport capacities. However, the model has weak points. First, the assumptions of perfect information and perfect competition are naïve. The upstream market is oligopolistic because of the geographical allocation on the one hand, and the creation of the Gas Exporting Countries Forum (GECF) on the other. GECF is similar to the Organization of the Petroleum Exporting Countries (OPEC) and it is to be assumed that the purpose of GECF is to coordinate global production and influence the prices. Consequently, the market situation is far from being perfect competition.

The GASTALE I model (Boots, Rijkers, & Hobbs, 2004), in contrast, assumed an oligopolistic upstream and downstream market. It targeted the role of DSO and their interaction with suppliers. It is designed in a two stage game with Cournot competition. In both sub-games, the optimization is done by profit maximization, whereby the upstream market, i.e. the suppliers, is regarded as Stackelberg leaders which assumes perfect information (Anderson & Engers, 1992) which also leads to the possibility of price discrimination. The model found that both – upstream and downstream – markets are well described as oligopolistic structures. Further, it was found that an increasing number of DSO leads to lower prices but also to no profit for DSO. In the case of two oligopolies, double marginalization takes place which increases the prices. Boots et al. (2004) surprisingly conclude that vertical integration would decrease the customer prices. That conclusion is bizarre, taken into account that the liberalization has the goal to introduce competition which was known in 2004. The simulation analyzed the scenario of perfect competition and came to similar conclusions. It is therefore questionable why the authors opted to recommend vertical integration. But this is not the only shortcoming. The model assumes perfect information but does not use results from one simulated period in the succeeding one. Further, the model assumes only inner European trade is only from producer to buyer and choses production as well as import amounts by profit maximization.

GASTALE II[2] is an improved model derived from GASTALE I. It was improved Egging and Gabriel (2006). The authors examined the influence of market power of the suppliers. Market power was modeled by the ability of strategically hold back quantities to increase the price. The downstream market was assumed to be in perfect competition. It was shown that market power increases customer prices, which is known from microeconomic theory (Varian, 2001). Further, it was concluded that an increase in pipelines and storage capacity leads to lower prices and decreases the effect of the market power. However, the capacities do not solve the problem of import dependency and with the creation of the GECF, market power of the suppliers is likely to increase. Other shortcomings from the first GASTALE remained (see table 1).

The fourth model in this analysis is a nonlinear model called NATGAS (Zwart & Mulder, 2006). It captures the market structure in a very detailed level, simulating producer, TSO, SSO, DSO and consumer. The results show an increase in investments of capacities, especially transmission from North African countries to Europe, an increase of inner European production until the gas reserves deplete and a gradual increase of prices driven by increasing demand and eventually decreasing indigenous production in the long-term. The model maximizes profit of every agent and assumes perfect information.

[2] The indexation of GASTALE (I-III) is done within the context of this thesis in order to lead the reader through the development of the model and does not reflect the official titles

Another stage of the initial GASTALE is provided by Lise et al. (2008). GASTALE III improved the shortcoming of no periodical interconnectedness. Thus, it uses investments decided on in precedent periods. The improvement enabled the authors to analyze the effect of demand and supply on investments. It was found that transport capacities and LNG capacities are needed. Further, competition in the downstream market within Europe will increase. Additionally, the demand affects disproportionately the need for investments and the price[3]. Furthermore, price differences within Europe occur because of the distance to the supplier and therefore lowest prices will be found in Turkey. The shortcomings of this model were mentioned above and can be inferred from table 1.

The last and most influential model, GASMOD (Holz, von Hirschhausen, & Kemfert, 2008), follows the precedent models. It is a two stage game using nonlinear programming. It includes the upstream and downstream market. However, the upstream market is more detailed than in other models since it takes into account indigenous production of EU member states (e.g. Germany, Austria, Italy). In each sub-game, the agents maximize their payoffs whereby inner European trade is included as well. The simulation results show that the market structure in both markets is best described with Cournot competition, i.e. oligopolistic market structure and that transmission capacities are a bottleneck.

In the analysis above, the most influential models of the EU gas market are presented. However, all models are optimization models. All of them follow a purpose and served well to answer the respective research questions. Nevertheless, some strong assumptions are underlying these models. First and by far a big shortcoming is the assumption of perfect information. All six models optimize the profit which assumes that there is a maximum. While consenting that the primary target of a company or an agent is to maximize its profit, it is questionable if that is happening by careful calculation of the market response (price elasticity of demand) given a certain price either based on price setting (Cournot competition) or quantity setting (Bertrand competition). Further, information of cost functions needs to be known. Simply put, the authors of the model base decision rules on information the agents in reality cannot have. Thus, the models derive from "the presumption that the system has a particular equilibrium or equlibria, or that any equilibria are stable" (Sterman, 2004, S. 519). Hence, the dynamics of the system are not regarded which can also be seen in the fact that four models are static. Simulation results of one period are not used for the succeeding. From a technical side of view, it also needs to be mentioned that the nonlinear programming models are based on the Karush-Kuhn-Tucker condition, which assumes convexity or requires the authors to use convexification which might change crucial relations within a system.

Model [no. citations[4]]	Type	Focus	Results	Critique
EUGAS (2004) [21]	Linear programming	• Optimal supply • Change in production and transmission capacities	• Diversification of supply needed • Investments in production and transport capacities increase	• Assumes perfect information and perfect competition • Linear relations • Includes unknown reserves in Europe • Static • Equilibrium based
GASTALE I	2 stage Mixed complementarity	• DSO and supplier interaction	• Double marginalization leads	• Assumes perfect information

[3] The authors give the example if demand increases by 20%, investments should rise by 30% and price increases by 10%

[4] According google.citations

(2004) [76]	model using nonlinear programming	• Production quantities and profit maximization	to increased prices • Vertical integration is favorable	• Inner European restriction • Static • Equilibrium based
GASTALE II (2006) [67]	2 stage Mixed complementarity model using nonlinear programming	• Market power • Consumer prices	• Market power of producers increases prices • Storage and transmission pipeline capacities decrease market power of producers	• Assumes perfect information • Storage and transmission does not solve the problem of import dependency • Inner European restriction • Static • Equilibrium based
NATGAS (2006) [21]	Mixed complementarity model using nonlinear programming	• Behavior of producers, TSO, SSO, DSO and consumer	• Transmission capacities to Africa increase • Prices increase gradually • Inner European production increases • Competition lowers prices	• Assumes perfect information • Equilibrium based
GASTALE III (2008) [38]	2 stage Mixed complementarity model using nonlinear programming	• Effect of supply and demand on investments into transmission and storage capacities	• Transport capacities are needed • Intra EU competition increases • LNG will expand • Increasing demand means increasing investments and prices	• Assumes perfect information • Inner European restriction • Equilibrium based
GASMOD (2008) [77]	2 stage Mixed complementarity model using nonlinear programming	• Type of competition	• Cournot competition • LNG increases • More competition decreases price • Transmission as bottleneck	• Assumes perfect information • Static • Equilibrium based

Table 1. Existing Models of the EU natural gas market

Taking into account the complexity of the EU gas market and the pace of changes of the institutional framework due to liberalization and the very nature of the gas demand (at least partly seasonality based), a particular equilibrium is unlikely to exist. Consequently, it is doubtable that linear and nonlinear programming is the right methodology to use. The problem presented at the beginning – the inner European trade and the changes due to the scenarios – has several characteristics that fit to the SD Methodology. The most important characteristics are the pipelines and storages. Those can be presented as stocks and flows whereby the stock variables are crucial variables on basis of which decisions are taken. They indicate how much gas is currently stored in the country. The flows – in form of pipelines – change the level of the stock and are influenced by the decisions derived from the stock level. Another reason why SD is appropriate is the immediate response of the existing system in form of feedback. The availability and demand of the gas will influence the price and the price has an effect on import, export, consumption and production. Last, assumptions taken by nonlinear programming are not necessary: the premise of perfect information and the existence of equilibria.

System Dynamics Model

Data Collection

The biggest data collection concerning the European natural gas market was found to be EUROSTAT. The environment and energy statistics provide a large database concerning quantities and consumption, prices and heat degree days. Therefore, most of the data origins from this data base. However, the data was not always consistent. In cases of inconsistency, information provided in the import tables built the basis for further calculations. The respective export data was inferred. In that way the data was cleaned and made consistent for simulation. This paper analyzes the gas flows of the following countries which will be referred to as "Inner Europe":

Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Italy, Latvia, Lithuania, Luxembourg, Hungary, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, United Kingdom, Norway, Croatia, Turkey

"Outer Europe" refers to the following countries which were identified by Eurostat data in combination with the pipeline network map by European Network of Transmission System Operators for Gas (ENTSOG) for determination whether the country is proving gas via pipeline, LNG or both. The countries providing natural gas via pipelines are:

Russia, Algeria, Libya, Turkmenistan, Uzbekistan, Iraq[5]

The countries considered as possible LNG exporters are:

Egypt, Nigeria, United States, Trinidad and Tobago, Oman, Qatar, Arab Emirates, Yemen, New Zealand, Algeria, Libya.

Data on consumption is divided into residential consumption derived by heat degree days (HDD) from Eurostat and commercial consumption which accounts for every non-residential consumption of natural gas. The distances between countries bases on the average distance between countries calculated on the basis of maps.google. The capacities used in the model where taken from Gas Infrastructure Europe (GIE) and all GIE related organizations. Pipelines and thus neighboring countries derive from the pipeline network map provided by GIE and ENTSOG. The capacities for import and export via pipeline between European countries were taken from the Gas Transmission Europe (GTE) data base which was provided twice a year beginning in May 2010. Only the cross-border capacities were taken into account. Inner country and virtual capacities were not regarded. GTE is the European organization representing TSOs. Gas Storage Europe (GSE) provided data about all storage facilities in Europe and represents all SSOs. Gas LNG Europe (GLE) provided import and export capacities concerning gasification of LNG. GLE represents LNG terminal operators in Europe. The data provided by GIE was in specific measures and needed to be converted into the main measure of the simulation. The conversion table in the appendix shows the values taken from the different organizations and Eurogas.

[5] Switzerland and Ukraine also provided gas via pipelines but the share is below 1% of the total imports. Therefore these two countries were excluded

Dynamic Problem

The focus of the thesis was already stated in the introduction: The inner European trade measured in the variables of import and export. The focus lies on the inner European trade and the choice of the trade partner. Consequently, the outer European trade volumes need to be subtracted. Figure 1 illustrates the refined reference mode, i.e. the total inner European imports and exports.

The time period in focus is January 2008 until July 2011. The period was chosen based on data availability. The time is tracked on monthly basis. Three groups of countries derive from an analysis of the import graphs. First, there are European countries only importing outer European natural gas. This group consists of Bulgaria, Latvia, Austria, Lithuania, Finland, Estonia, Portugal, Romania and Turkey. The second group shows oscillations. In most of the cases the oscillations grow as time goes by and the oscillations peak in the winter months. France in figure 1 is a good example. In the beginning of the period, the imports are going down. The lowest imports are reached in August/September and increase in the following months again to a peak in January and December. The lowest import level is September 2011. In this month, the imports amount 47.171 TJ. The highest imports can be seen in March 2011 with 228.000 TJ. Similar behavior of the import curve can be seen in Belgium, Italy, Germany, Luxembourg, Ireland, Poland, Slovenia, Sweden and UK. The country's import curves show similar behavior, i.e. pattern but do differ significantly in magnitude and volume.

The third group consists of countries whose import curve is either very stable or zero. Those countries are Czech Republic, Hungary, Greece, Netherlands, Denmark, Norway, Spain and Slovakia. It needs to be mentioned that Slovakia's imports differ due to the Russo-Ukranian conflict mentioned before. The reference modes concerning exports are different. First, in all case besides of Norway, Denmark and Netherlands, the exports are significantly lower than the imports. Figure 1 shows the substantial difference: The blue graph is much lower than the red one. The reason for that difference is the abundance of natural gas reserves in those countries. Nonetheless, three groups can also be inferred. First, those countries which have oscillating exports.

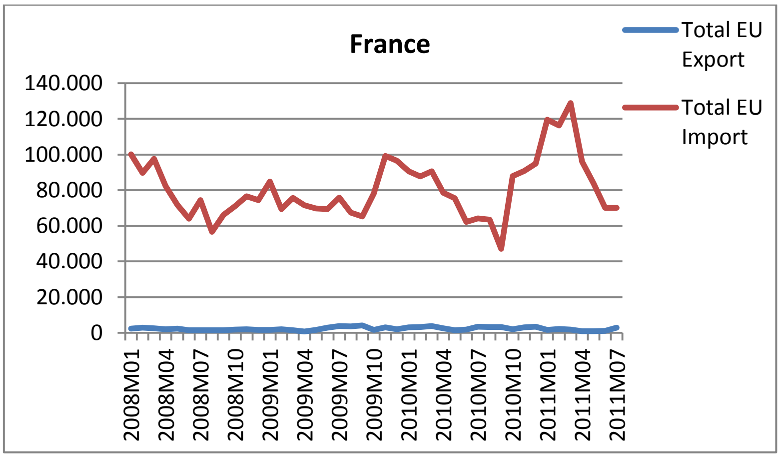
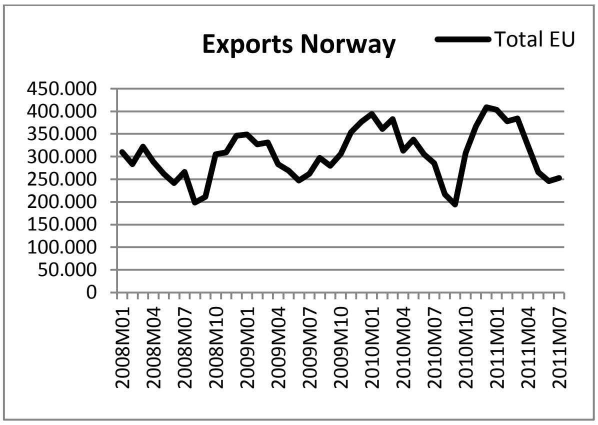


Figure 1. Refined Reference Mode

Figure 2 shows the example of Norway. The export curves peak in the winter months and Belgium, Denmark, Italy, Netherlands and Austria show a similar pattern. The second group of countries consists of Finland, Sweden, Estonia, Ireland, Greece, Bulgaria, Latvia, Lithuania and Romania. These countries do not export. The third group is the collection of different kinds of oscillations, patterns that are flat and straight and suddenly skyrocket and go back to the initial level. Figure 3 shows the exports of Turkey. Other countries that belong to this group are Germany, Spain, Czech Republic, Luxembourg, France, Poland, Croatia, Portugal, Slovenia and UK.



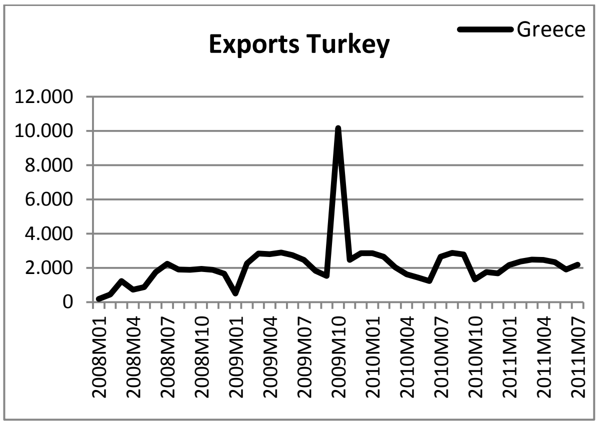
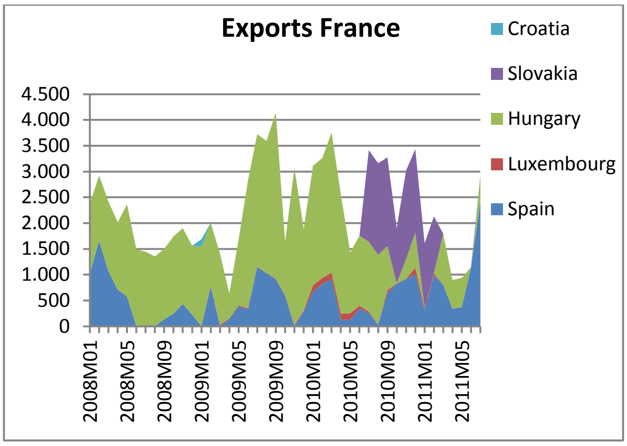


Figure 2. Exports of Norway

Figure 3. Exports of Turkey

These two curves are the main focus of the present thesis. Nevertheless, it is only one side of the coin. As stated earlier, the inner European trade is to be modeled. That does not only involve the total amount of imports from and exports to European countries but also the choice of the apparent trade partners. That means, the model has to show which amount of natural gas was sent from one country to the other. The curves presented in figure 1, figure 2 and figure 3 are each based on the sum of the imports and exports respectively. In order to identify the trade partners, those numbers need to be broken down. That is done in figure 4 for the exports and in figure 5 for the imports of France. As can be inferred from the export graph on the left side, France is sending out a lot of natural gas to Hungary and Spain. Only little gas is sent to Luxembourg and Croatia. The fifth trade partner of France is Slovakia which was the main trade partner in the period of July 2010 and February 2011. The imports of France are mainly based on Norwegian and British natural gas, whereby Norway is the main trade partner. Germany and Spain also appear as supplier but their contribution to the total imports is rather small.

In conclusion, the dynamic problem can be defined as the inner European imports and exports traded from one of the 28 defined European countries to another in the period of January 2008 until July 2011. Hence, the focus is on the flows between the European countries.



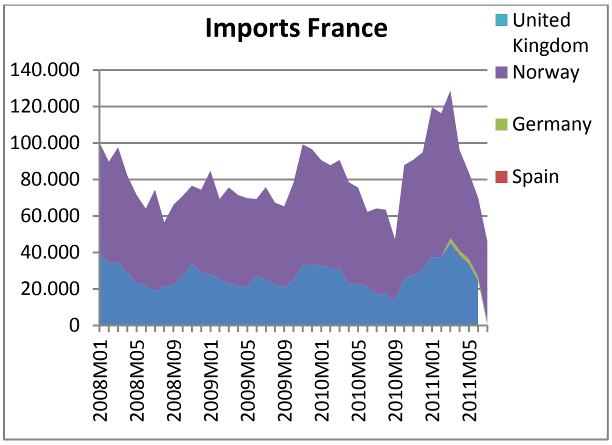


Figure 4. Export Split Down for France

Figure 5. Import Split Down for France

Dynamic Hypothesis

Natural gas imports are demand driven. The demand consists of two types. The residential consumption, which is solely used for heating purposes, is very predictable. The demand grows in the winter months and decreases with rising temperature. The other part of the consumption is the commercial consumption. Demand for gas used for energy generation, as well as for other production and chemical use, is less predictable and very price elastic as mentioned before. Information about both types is publicly available and thus different tools for future demand exist (Balestra & Nerlove, 1966; Gutiérrez, Nafidi, & Gutiérrez Sánchez, 2005; Erdogdu, 2010).

The need for gas can only be met by inland production or import. Due to the allocation of gas reserves only two countries are self-sufficient: Norway and Denmark. The other countries have either limited production or no access to gas reserves and need to import additional amounts of gas. That led to long-term contracts (LTC) with mostly outer European countries. These LTCs led to lower import prices and security of supply. Due to ToP clauses, monthly import amounts were fixed and made planning easier since the market actors knew which amounts of gas would flow into the country. The liberalization process did not change these contracts and the incumbent market actors still have agreements and ongoing LTCs. Thus, market actors are performing well in predicting natural gas consumption, they decide on inland production and due to LTC, the market actors have some information about how much natural gas will be delivered in the next month. However, LTCs do not cover the whole demand. This excess demand needs to be covered by additional trade. Market actors first look at inner European trade possibilities because of (a) the trade union and the omission of customs, (b) the shorter transportation and thus lower cost for transportation and (c) the existence of subsidiaries in the European countries. Then, if the inner European supply is not high enough, outer European negotiations start.

As stated before, only a few European countries have access to natural gas reserves. However, that does not mean that only a few countries trade. Due to LTC and mistakes in the planning, it can happen that additional gas is stored in the country. This gas is available on the market. Importing countries choose their preferred trade partners on basis of two criteria: (1) the price and (2) the availability. The first criterion is exogenously given by the 6 month average prices of a country. However, the amount of gas stored in the country has a nonlinear effect on the price and leads to a rapid increase. Albeit the price is usually the main indicator, the availability of gas also needs to be regarded and serves as the second criterion in the trade partner choice. The attractiveness of a supplier does not solely depend on the price but also on the availability of the gas. For instance, if Luxembourg offers 1 TJ of gas for a little lower price than the Netherlands, it is not said that Luxembourg needs to be preferred. Simply put, if the demand is ten times higher than Luxembourg's offer, the transaction cost and organizational planning for the cross-border transmission is not worth to prefer it. Netherland's higher supply would balance the criteria. Having chosen a trade partner leads to negotiations. At that point, it can happen that several countries have chosen the same supplier as their preferred trade partner. In such a situation it is likely that either the amount of gas available or the export capacities are not high enough to meet the demand. The supplier needs to decide how to allocate the available gas. This is done by a priority measure – the trade relations. Trade relations are determined by the amount and frequency of natural gas traded. It can be seen as a loyalty program – the more gas is bought and the more often a transaction takes place, the better are the trade relations and a country becomes the preferred client of a supplier. In that way a trade is not only determined by the importer but also by the exporter.

The trade leads to a decreasing stock of stored gas. The lower level of gas decreases the availability of gas and increases the price. Both effects lead to a lower attractiveness of the supplier as it otherwise would have been. The country would not be the number one trade partner. Not being the preferred trade partner does not imply that no transaction takes place. First, negotiations will only happen between neighboring countries and second, if the first best trade partner cannot satisfy the demand, the second best and if needed even further ranked trade partners will be chosen.

The importer, on the other hand, increases its stock of stored gas, which leads to decreasing prices and higher availability. Both effects increase the attractiveness of the country and it ranks higher as a preferred trade partner as it otherwise would have been ranked.

The description of the model already included some explanations concerning the variables. However, it did not explicitly mention which variables are endogenously determined. Table 2 presents the model boundary chart. It shows on the left hand side the main variables that are derived from the system's behavior. Other variables are exogenously determined and fed in. These variables are production, capacities and consumption. It is for sure interesting and apparent that some feedback connections between exogenous and endogenous variables can be identified. For instance, price and consumption is one clear link. However, the focus of this thesis is on the inner European trade and thus those connections were not regarded.

Endogenous	Exogenous	Excluded
Choice of Trade Partner	Capacities (Transmission, Storage, Production)	Strategic Storage for Forward Trading
Price	Production	Gas Quality
Import and Export	Consumption	Capacity Auctions
Inner European Trade Volume	Transport Distances	Gas Reserves
Trade Relation		Investments

Table 2. Model Boundary Chart (Sterman, 2004)

The underlying assumptions of the model are partly shown in the excluded variables. Firstly, the gas quality is assumed to be constant and the same in all countries. Secondly, swaps and strategic storage of gas as transactions of energy trading are not regarded. Investment decisions for capacity increase or exploitation of gas reserves are also not regarded. The capacity of pipelines and LNG are fed in externally and it is assumed that there is enough gas for every demand in the model. In case it is not satisfied within Europe, the countries will ask outer European countries.

Causal Loop Diagram

The dynamics described apply to all 28 countries. Because of its complexity the whole model was put into arrays (Vensim© language: subscripts). The causal loop diagram (CLD) in figure 6 explains the dynamics for the case of two countries. The central stock variable on basis of which decisions are derived is the "Stored Gas". The stored gas has an inverse effect on the price which is one of the criteria that defines the attractiveness as a trade partner for other countries. The lower the price, the higher the attractiveness. The higher the attractiveness, the longer a country carries the status of preferred trade partner which leads to higher exports and thus lowers the level of stored gas. That is a balancing loop, B1, based on the price. The second balancing loop, B2, is based on the availability of gas within one country. The detailed description of the attractiveness measure will follow in the next section. One more balancing loop, B3, can be identified. Some countries have a desired stock level for security reasons. An increase in demand can be observed if the desired stock level exceeds the amount of stored gas within the country. The higher demand, in turn, leads to more imports which increase the stored gas and closes the gap between desired and actual level.

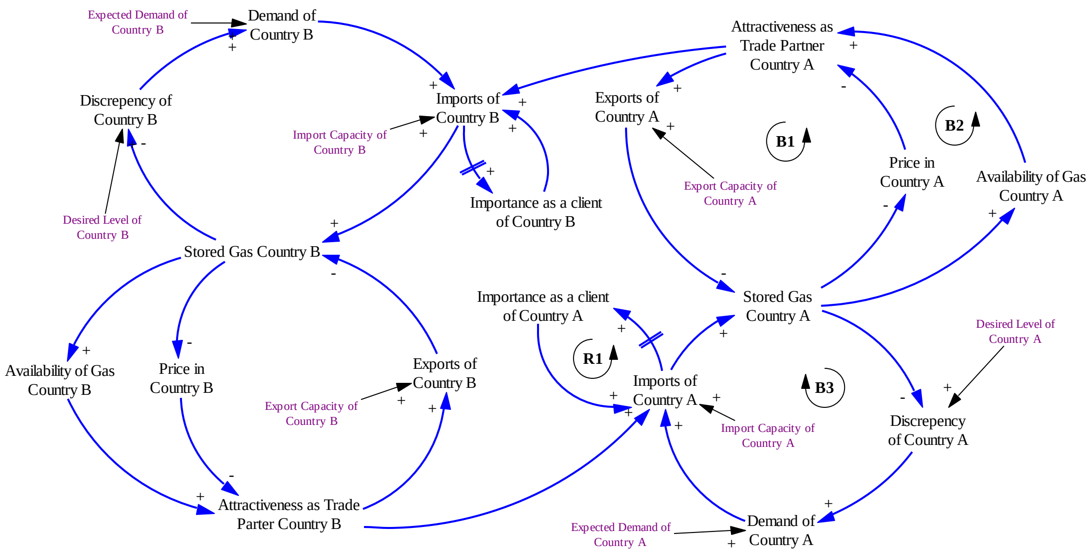


Figure 6. Simplified CLD for two countries

Further, the model includes one reinforcing loop, R1. This reinforcing loop is the trade relations loop. It tracks the amount of natural gas bought by one country from one supplier and ranks it. This rank is then used as a prioritization measure for capacity allocation in case the demand exceeds the export capacity or availability of gas of the supplier. Simply put, the more and the more frequently a country bought from one supplier, the more the country can obtain the next time. On the other hand, it also needs to be mentioned that a country can easily lose the high prioritization measure if it did not buy gas from the incumbent supplier several months. Consequently, history matters and the performance of one point in time influences the following.

These four loops produce the main dynamics in the model at hand. Figure 6 however shows some more loops. Those loops appear because of the 28 country structure and play a smaller role. Figure 7 emphasizes these loops: The level of stored gas influences the attractiveness of country A as a trade partner. Country B imports from country A and increases its stock, which in turn increases the attractiveness of country B as a supplier for country A. The gas would circulate between both countries. However, that only holds true if now consumption is taking place. Only little amounts of gas circulate due to those feedback loops since there exogenous consumption will also decrease the stocks.

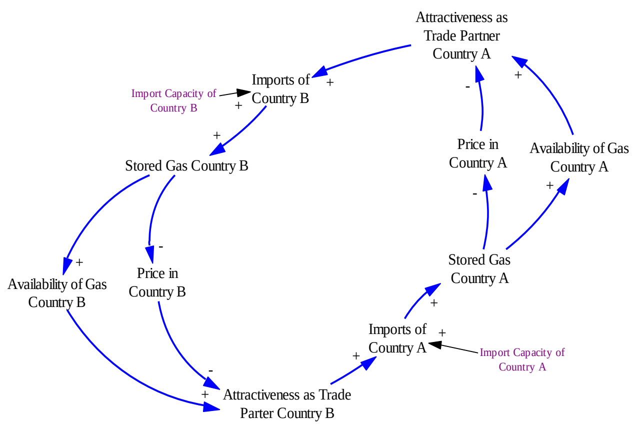


Figure 7. CLD of less important loops

As mentioned before, the 28 countries are put into an array structure. Thus, figure 6 and figure 7 can be misleading concerning the model. Therefore, at that point, we want to show a simplified stock and flow diagram (SFD) that makes it easier for the reader to understand how the model is constructed. It is of enormous importance to change the way of thinking from a one dimensional SD model to a subscripted model. Figure 8 shows the main difference. In the complete model, the reader might find feedback loops from one flow to another as shown on the left side of figure 8. Due to the subscripted variables, however, the flow of one element influences the flows of other elements and not its own inflow. That is shown on the right side of figure 8 .

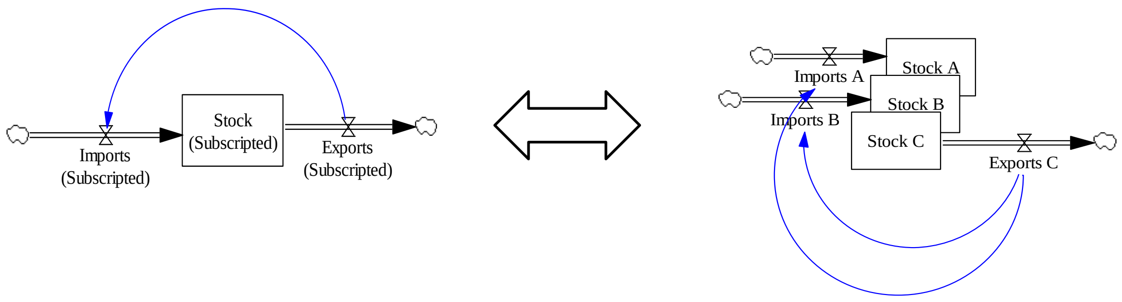


Figure 8. Explanation subscripted SFD

Special Features

The model has two special features or calculations that are the heart of the model. On the one hand, the importing countries rank their trade partner according to price and availability of gas. On the other hand, the exporting countries allocate their gas supply and export capacities according to a prioritization measure. These two features are explained in the following.

Calculation of the attractiveness measure

Having introduced the difference between subscripted and one dimensional models and having explained the main dynamics of the model, the reader now needs to understand the main decision rule of the model: The choice of the trade partners which is based on an attractiveness measure. In the model, this attractiveness measure is called “Ratio Availability Rank to Price Rank”. The name makes it already clear: it is a ratio between two ranked variables.

One variable is the price per TJ. This price derives from the half yearly prices and the average distance between the countries. Hence, the price is not simply subscripted but has 2 subscripts: the supplier or exporting country (subscripted as “FromCountry”) and the buyer or importing country (subscripted as “ToCountry”). Both subscripts have the same elements which are the 28 countries. The variable “Market Price Matrix per TJ” is therefore a matrix which indicates the sum of the price per TJ and the transportation of that TJ from one country to another. This matrix is then ranked for each importing country. Figure 9 shows an example: The black dashed line shows the minimum price, thus the preferred price. In the beginning of the time series of figure 9, county B (the red line) has a lower price and thus would be ranked first. However, in month 5 of 2008, country A offers a lower price and would change its rank from initially second to first. In that example, the reader took the view of one importing country. Country A and B are suppliers. In the variable “Market Price Matrix per TJ” this ranking is taking place for 28 importing and 28 exporting countries. Thus, a matrix of 28x28 results from that step whereby the exporting country with the lowest price is ranked first. The ranking is ascending.

The same is done for the availability of the gas – the second variable needed for the attractiveness measure. A certain amount of gas is available for trade. This time, it is preferable to have more gas available. Nevertheless, the ranking is ascending again. That means, the exporting country which offers most gas on the market is ranked highest.

Two ranked matrices result from both variables – price and availability. Table 3 shows an example of one ranked price matrix. As can be seen in the table, the first column is the importing country (subscripted ToCountry), which ranks the supplying countries according to the price. Since the price consists of price and transportation, it is often the case that the importing country ranks itself first. This mistake is corrected by a supporting matrix which introduces a fact that countries only trade with neighboring countries[6].

The two ranked matrices concerning availability and price built a ratio whereby the availability rank is divided by the price rank. table 4 shows an example. As can be inferred, the higher number within the matrix is preferable. Again, table 4 is an example and does not show the ranking of a certain country rather than the connection between the ranks. In orange the same number is highlighted. It shows that this ratio makes possible a comparison between two countries. In the orange highlighted cells, two cases are shown. In the first case, a country ranks second in the availability. That means two other countries supply more gas on the market but the supplier balances this disadvantage by offering the lowest price. In the second case, the supplier ranks best in the availability measure. That means the supplier has rank four but does not offer the lowest price. Thus, the overall measure is lower. The overall measure defines the preferred trade partner for the importing countries and defines which country is asked first for gas. This ratio can be seen as attractiveness measure as mentioned before and is one of the features of the model.

Figure 9. Example Price Development

From ---> ↓To	Belgium	Bulgaria	Czech Republic	Denmark
Belgium	1	4	3	2
Bulgaria	4	1	2	3
Czech Republic	4	3	1	2
Denmark	2	4	3	1

Table 3. Ranked Price Matrix

		Rank			
	Price ---> ↓Availability	1	2	3	4
Rank	4	4	2	1,333333	1
	3	3	1,5	1	0,75
	2	2	1	0,666667	0,5
	1	1	0,5	0,333333	0,25

Table 4. Attractiveness Measure

There are at least two shortcomings of that feature: (1) the ordinal scale resulting from the ranks does not take into account the differences between the prices and availability and (2) the specific functioning of the VECTOR RANK function of Vensim©. In case of the ordinal scale, it can be stated that the dynamic calculation leads to a change in the rank as soon as the difference is zero. Thus, the difference is indirectly taken into account because of the dynamic and simultaneous simulation. The second shortcoming is more severe. VECTOR RANK performs weak as soon as two elements have the same value. The manual of Vensim© states: "If two elements are the same the will arbitrarily be assigned contiguous ranks." (Vensim, Vensim Manuals, 2006). This shortcoming is tried to be worked around by multiplying the ranked matrices with support matrices and re-rank the numbers again. However, it is one of the less sophisticated features of Vensim©.

[6] According to the ENTSOG pipeline network

Allocate by priority

The second feature of the model is the introduction of trade relations and the use as a prioritization measure for capacity allocation. It is a reinforcing loop in the model. So far, the trade partners were identified and a matrix of trade partner preferences was generated. It can happen that several countries want to buy gas from the same supplier but the supply is not sufficient to meet the need. In order to avoid negative stocks, excess demand and an arbitrary allocation, a procedure needed to be found in order to allocate the existing capacities. For a proper allocation the following requirements were identified:

- *In case of sufficient supply, all importers should receive the demanded amount of gas*
- *In case of shortage, the allocation should happen according to a key which leaves relatively low amounts of gas to low priority countries and more amounts to high priority countries*
- *The exporters cannot supply more than their capacities*
- *All amounts are positive or zero*
- *No physical loss: the deliveries from all suppliers needs to equal the sum of all imports*

These requirements hold true for the Wood logarithm which is implemented in the ALLOCATE BY PRIORITY function of Vensim© (Vensim, Vensim, 2012). The logarithm allocates the available export capacities among the buyers according to their relative priority. This priority measure is the trade relation which was modeled as an information stock as shown in figure 10. The trade relation ranking is a ranked matrix of exports which tracks how much natural gas was sent out to a country. Again, the less sophisticated feature of the VECTOR RANK function needs to be solved. That is why the “Support – Only Traders” Matrix will adjust the trade relation ranking (countries that did not buy any gas are ranked zero). The trade relation period is the time span which defines how fast the priority of country deteriorates in case no trade is done.

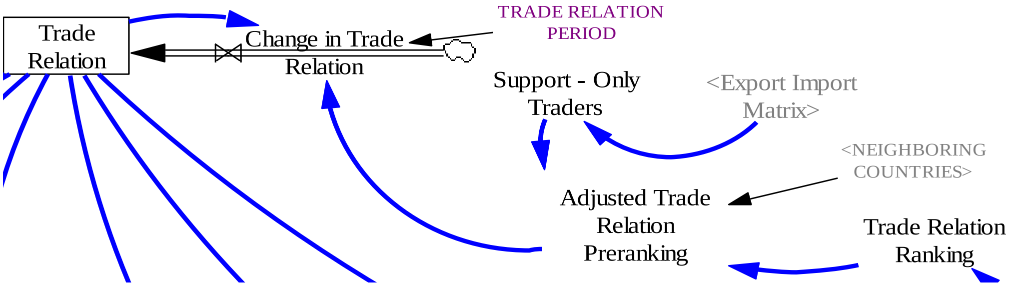


Figure 10. Trade Relation

The trade relation measure is then fed into the ALLOCATE BY PRIORITY function as priority parameter and determines the amount of gas a country can buy from a supplier. Simply put, the more a country buys, the better is the trade relation and the higher the trade relation the more a country can buy as it otherwise could have bought.

Taken all parameters stay constant, the tracking and ranking of the traded amounts would lead to path dependency which would lead into a lock in. The country that bough in the beginning the most, will receive the most under the assumption that the sum of supply is always lower than the demand, and no other shocks are given. However, the demand depends on an exogenous variable and thus the system is shocked. It happens, for instance, that the demand decreases and in that time, countries lose their high priority status. Nevertheless, it is a good feature of the model and an easy way to dynamically show how history matters (Sterman, 2004) due to accumulation of the ranking of previous trade volumes and how structure and the initial allocation interacts with the behavior of the system.

Model Analysis

In this section we present the analysis of the model. We tested the model for soundness and validity. Aside of the reference mode comparison and a shock test, which we are presenting here, we also conducted the following tests: test for endogenous behavior ("cutting the loop"), extreme value test, unit check and sensitivity analysis. We did not find any severe flaws and concluded that the model behaves consequential.

Reference Mode Comparison

The dynamic problem is defined as the inner European imports and exports traded from one of the 28 defined European countries to another in the period of January 2008 until July 2011. As stated in the beginning, this definition leads to two different reference modes. First, does the total amount of imports and exports fit to the simulated results? In the second step, it then needs to be checked if the flows between the European countries can be accurately reproduced by the model.

The first impression of the import comparison was surprisingly good. However, it has to be stated in the beginning that 19 of the 28 countries have a high share of outer European gas imports, i.e. these numbers are exogenously generated and thus are not representative for the comparison. However, nine countries do not belong to that group and consequently can be analyzed concerning the simulated data. Those countries are Belgium, France, Sweden, UK, Denmark, Ireland, Luxembourg, Norway and the Netherlands.

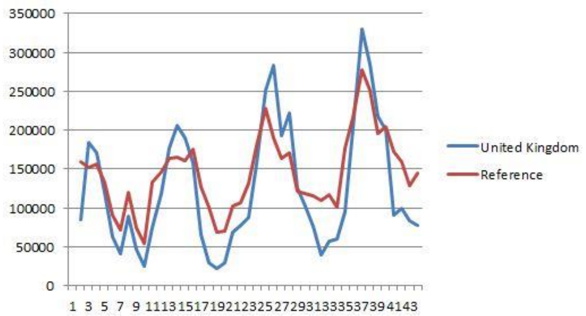


Figure 11. Reference Mode Comparison of Imports for UK

Figure 11 shows one of the comparisons. As can be inferred the fit is very accurate. The fit of the simulated data (blue line) to the reference modes (red line) is evident for the following countries: Belgium, France, Sweden, UK and Norway, whereby the latter does not have any demand and thus no imports. The accurate fit is also supported by goodness of fit measures taken from Sterman (2004). These are shown in table 5 R^2 shows that approximately 80% of the variation is explained. Theil's inequality statistic shows that there is a systematic error. The model and the historic data have the same phasing but differ in the amplitude and that there is a bias which should be fixed by parameter adjustment. However, the current simulation is the best fit.

The imports of Denmark, Ireland, Luxembourg and the Netherlands, on the other hand are less sophisticatedly reproduced. Figure 12 shows the case of Luxembourg. The question for the reason needs to be answered for by looking at the structure and the initial values of the model. In the beginning of the simulation, the data can be reproduced which is due to external data and outer European imports. The blue line starts to differ significantly from the reference mode (red line) as soon as Luxembourg does not get any outer European gas anymore. Luxembourg's simulated imports go down before it jumps suddenly up to 8500 TJ per month. It then falls again before it increases back. The reason for that different behavior tracks back to the initial trade relation. Luxembourg's trade relation with its preferred trade partner – Germany – is on a low level, and continues to decrease since Luxembourg's imports are based on outer European supply for the beginning of the simulation for 13 months. After this period, Luxembourg starts demanding within Europe. However its relative importance is small due to the low prioritization measure. Since the demand is not satisfied, a backlog is built. Eventually, Luxembourg gets smaller amounts of gas, so the trade relations go up and Luxembourg can satisfy some of the demand. The proof can be seen in figure 13. The blue line is the same as in figure 12. The red one shows a new simulation with a different much higher initial level. As can be inferred, the red line differs. However, the initial trade relations derive from the periods before 2008 and lead to good results for four countries. A change in the initial value does not lead to an overall improvement for the other countries. Ireland's simulated import curve, for instance, does not improve. In conclusion, the simulated total imports are replicated quite fairly. Some countries could be replicated quite well, most of the countries' imports, however, based on external data and some curves cannot be reproduced

Statistics	
MSE	2057744140
MAE	39741,17315
Correlation Coefficient	0,891315286
R^2	0,794442939
MAPE	0,310126245
MAE/Mean	0,275405718
RMSE	45362,3648
Theil UM	0,180444805
Theil US	0,429832692
Theil UC	0,409235722
UM+US+UC	1,019513219
Pearson Correlation	0,891315286
F-Test	0,002737621

Table 5. Goodness of fit measures

The next step is to compare the inner European flows. For that, a 28x28x43/time step – matrix needed to be analyzed. For that reason a macro was written. For further use of the excel file, please enable macros. The figures are directly taken from that file and only examples are shown here. For complete comparison, please use the excel file.

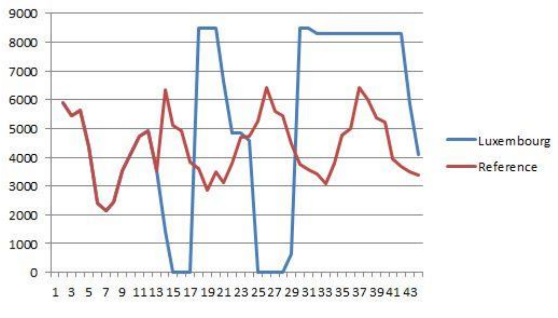


Figure 12. Reference Mode Comparison of Imports for Luxembourg

Figure 14 shows the example of UK which was already shown in ***figure 11***. Now, however, the total amounts are broken down to the flows. In the upper part of the figure, the historic data is shown. The lower graph shows the simulation results. It shows that the trade partner choice is very well replicated: the pink colored Norway is in both cases the main trade partner, the second best trade partner are the Netherlands in violet. A smaller role plays Belgium (blue). The example shown here is a very good replication of real world data. However, it is not the case for all countries of the study. Indeed, 18 countries are only mediocrely reproduced. Those countries are Belgium, Bulgaria, Czech Republic, Denmark, Estonia, Greece, Spain, France, Italy, Latvia, Lithuania, Hungary, Netherlands,Austria, Slovakia, Sweden, Hungary and Turkey. It is to be emphasized that not the trend of the curves were compared but the trade partners and the amounts traded. figure 15 shows the case of Sweden, where the real imports (top) is completely supplied by Denmark. The simulation, however, shows Norway as second supplier.

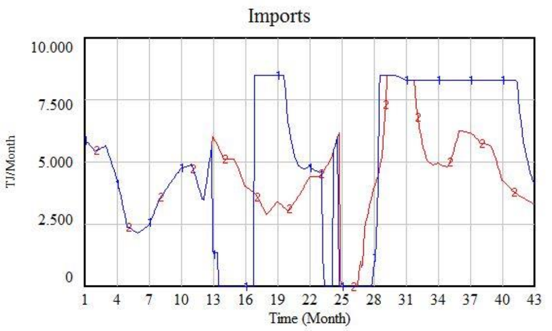


Figure 13. Simulation with low (blue) and high (red) initial trade relation between Germany and Luxembourg

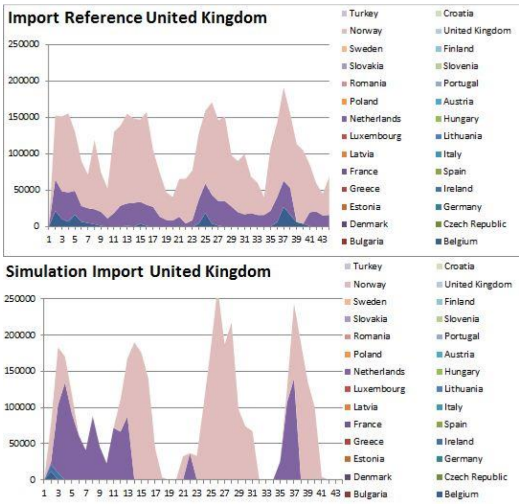


Figure 14. Import UK

The countries with a better fit are Germany, Ireland, Luxembourg, Poland, Portugal, Romania, Slovenia, Finland, UK and Norway. The main trade partners could be identified in those cases.

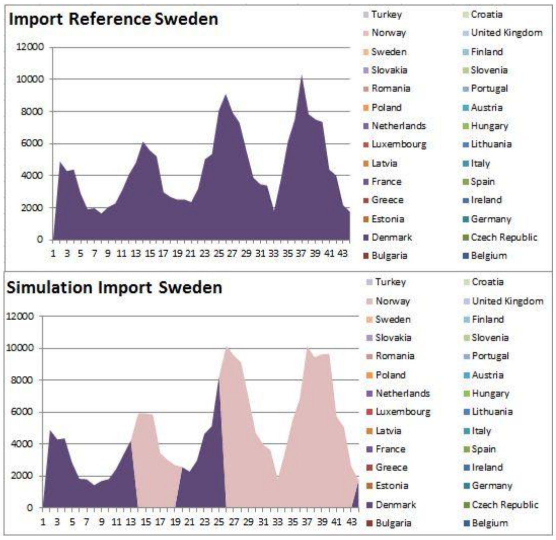


Figure 15. Imports of Sweden

Exports

The total number of exports can be compared to the situation for the imports: some countries can be reproduced very well, most of them do not trade or have some discrete event like exports and some country's reference mode cannot be reproduced. 14 countries do not involve in trade or have not real patterns to be reproduced. Those countries are: Bulgaria, Czech Republic, Estonia, Ireland, Greece, Spain, Latvia, Lithuania, Luxembourg, Poland, Romania, Slovenia, Finland and Sweden. The import curves of Denmark, Germany, France, Italy, Austria, Croatia, Turkey and UK cannot be reproduced properly. Turkey's exports serve as an example here (Figure 16). It can clearly be stated that there is no interrelation of the two curves[7].A rather good fit is shown in the exports of the main exporters: Netherlands and Norway. Their export curves can be very well generated by the model. Other countries whose exports can be reproduced are Belgium, Hungary and Portugal. Figure 17 shows Norway's exports. The red line is the reference mode. The blue line the simulation result. On the right side of the figure, the goodness of fit measures can be found. The extremely low values of the Theil's inequality statistics show that only little systematic errors appear and the model has the same trends as the data.

[7] Red = historic data, blue = simulation

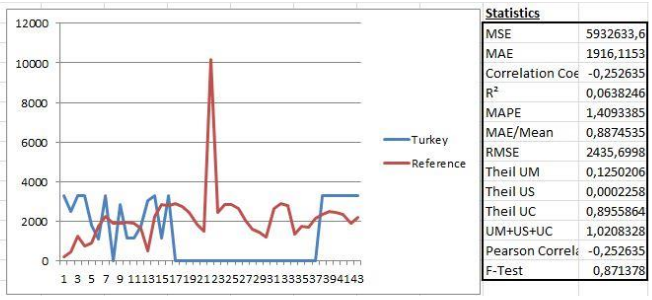


Figure 16. Reference Mode Comparison of Turkey's exports

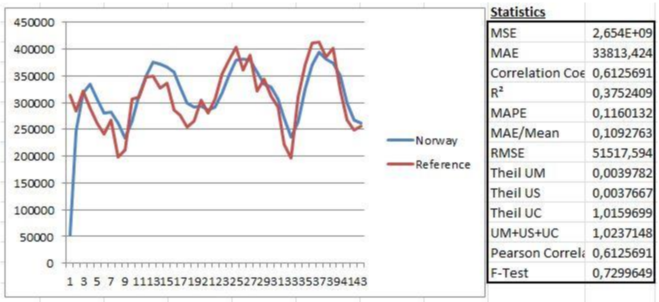
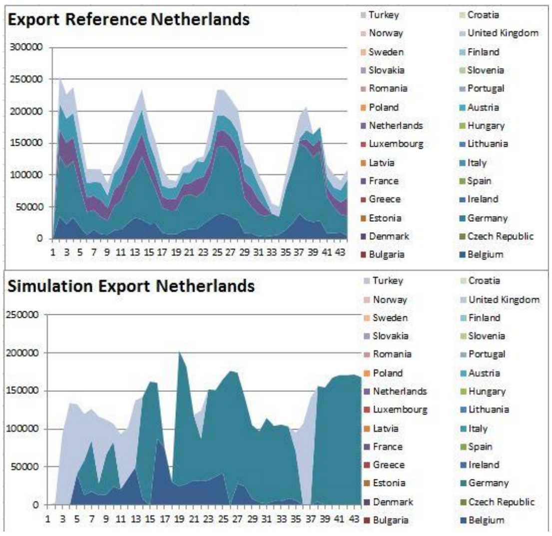


Figure 17. Reference Mode Comparison of Norway's Exports

As seen in the previous section, the choice of the trade partner needs to be analyzed as well. Figure 18 and figure 19 show the graphs of the two countries with the best reference fit: The Netherlands are on the left side in figure 18. The top (bottom) of the figure shows the reference data (simulation results). The main trade partners can be identified by the same color in both graphs: UK, Germany and Belgium. However, the real data shows France, which plays no role in the simulation. Figure 19 shows Norway. Again, main trade partners like Germany, UK and France are identified in both figures. However the real data on the top shows much more trade partners that are not considered in the simulation. In addition to the two countries shown in the figures above, France and Portugal can be replicated. However, the majority of countries cannot be reproduced.



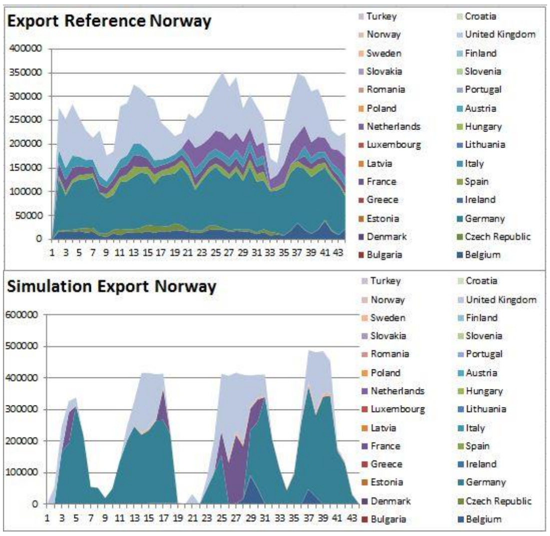


Figure 18. Detailed Reference Mode Comparison of Netherlands

Figure 19. Detailed Reference Mode Comparison of Norway

In conclusion, the model performs mediocre on accurately predicting and reproducing the trade partners. One reason is that the data shows trades between non-neighboring countries and one of the assumptions of the model is that only neighboring countries trade with each other. However, that is not the only reason. Nonetheless, a model that fails to accurately reproduce the reference modes and patterns can still behave consequential and thus can be used for analytical tasks.

Shocking the system in Equilibrium

One of the main needs of the model was to show the logical flow of the natural gas through Europe. In other words, if Hungary trades with Spain, the gas needs to flow through Austria, Germany and France and cannot happen immediately. The gas has to flow logically through the neighboring countries to the country in need. For that reason, the model was put into equilibrium. All outflows and inflows were put stable. The desired level of stored gas is precisely met. Only one country has some additional gas.

In case of a shock it is expected that the gas moves from the country abundant of gas to the country in need. That happens through a pull mechanism. That means the country in need starts demanding and eventually buying from its neighbors which creates additional demand of the neighbors. Thus, the demand is passed along until it eventually reaches supplier. This case is shown in two different scenarios. In the first, the country in need has only one direct neighbor and thus passes the whole demand to its neighbor and so on. In the second scenario a country with a lot of neighbors will be shocked and buys from different neighbors. The neighbors will also have the need to buy new amounts of gas. For that reason, the maximum amount of gas to be exported can amount the whole stock, i.e. there is no security level.

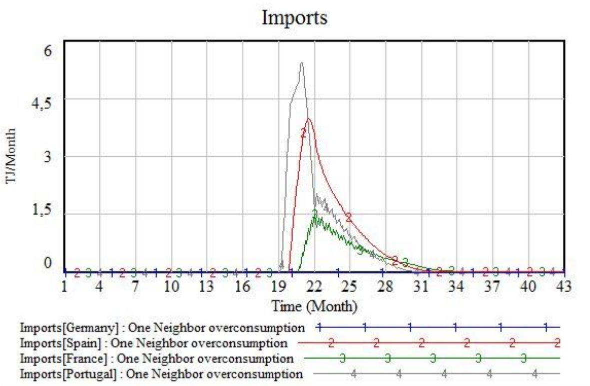


Figure 20. Shock Test: One Neighbor

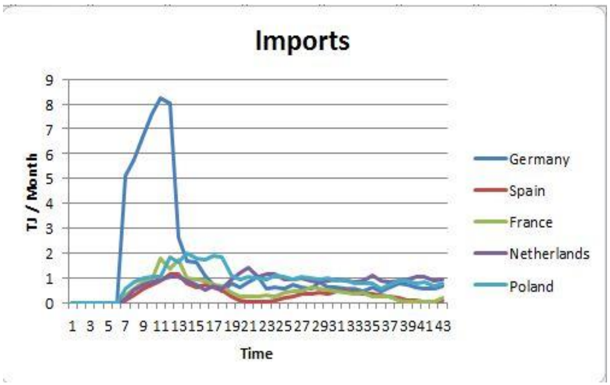


Figure 21. Shock Test: Several Neighbors

Figure 20 on the left shows the first case and figure 21 the second. As can be inferred from both figures, the country in need of gas, bought it from its neighbor in order to meet the demand. However, the lower amount of gas of the neighbor lead to demand and so on. The system behaves as expected. In the case of several neighbors some oscillations occur since the gas is bought from each other to satisfy the demand. In that case the less important loops shown in figure 7 come to play and having bought one additional unit of gas makes the country more attractive to its neighbors. Consequently, this one unit is passed around until finally additional amounts of gas reach one of the neighboring countries and closes the discrepancy between desired and actual level.

Scenarios

The omission of long-term contracts

The first scenario is the omission of traditional LTC. Even though the LTC play an important role for the security of supply (EU, 2004/67/EC), the evolution from traditional LTC with take-or-pay (ToP) clauses with a duration of 20 years to more price and quantity flexible contracts with shorter duration (3-5 years) is observed (Neuhoff & von Hirschhausen, 2005; Neumann & von Hirschhausen, 2004). Further, market mechanisms like gas release auctions redistribute the imported gas among different market players (Creti & Villeneuve, 2004). Thus, it can be assumed that the nature of LTC change from fixed priced, fixed predictive quantity long term agreements to very flexible price, flexible quantity agreements with significantly lower duration. In a very simplified view, the LTC will only guarantee the possibility of trade and therefore do not significantly change, compared to a market without LTC. Therefore, the question is to what extent the trade volumes change when LTC and consequently the predictable fixed gas imports are not present anymore.

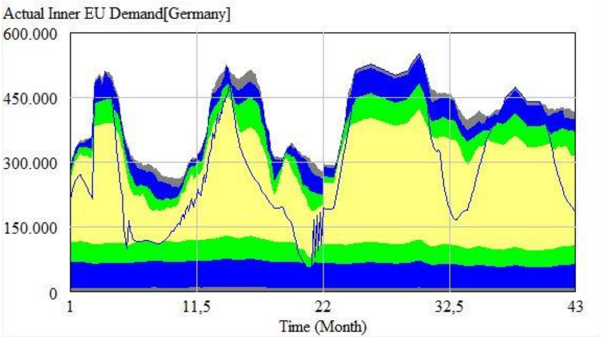


Figure 22. Germany's Demand without LTC

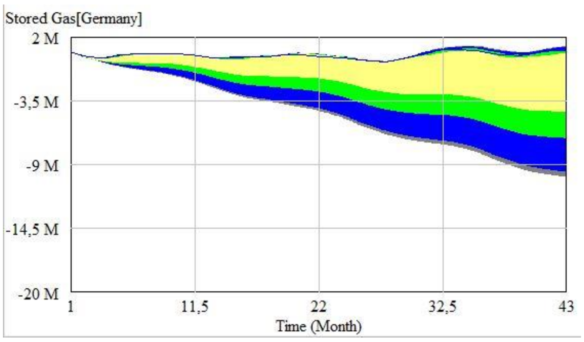


Figure 23. Germany's stored gas without LTC

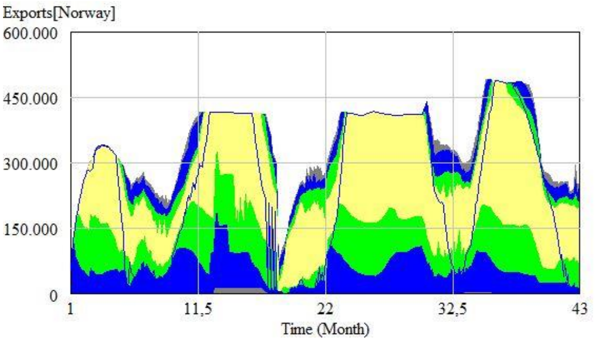


Figure 24. Norway's Exports without LTC

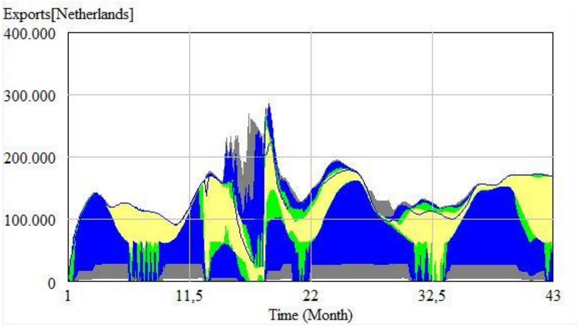


Figure 25. Netherland's Exports without LTC

The omission of LTC is implemented by a tuner variable which decreases the amount of pipeline LTCs. A sensitivity analysis shows the results. The colored areas show the distribution of different runs under changes of the value of the tuner. The yellow area shows where 50% of all simulation runs lie, green the 75%, blue the 95% and grey the 100% range. Figure 22 shows the demand of Germany in TJ per month. It can be inferred that in the winter months the demand stays the same. However, in the summer months the demand is likely to increase. This is due to backlog building, since the demand is not met. In the winter months there is no additional capacity, thus backlog is piled up. This is then to be closed in the summer months. Figure 23 shows the storage of Germany. As can be seen. The stock decreases over time, since a crucial part of outer European gas supply is missing. Figure 22 shows Germany's imports also measured in TJ per month. The figure looks like the demand but the distribution intervals of the sensitivity analysis is different. The imports are likely to decrease. If everything stays stable, not only Germany will demand more, but also other countries. That leads to lower gas amounts in Europe and thus to lower imports from outer Europe. The last figure on this page shows the exports of Norway. Figure 24 is measured in TJ per month and it can be seen that Norway's export capacities are reached. The summer exports will increase whereby the winter export capacity is completely taken. Figure 25 shows the exports of the Netherlands. It shows that in this case, some more capacity is available but the exports do not change in such an extent as Norway in the summer.

The conclusion of that scenario is the need for higher inner European consumption to balance the omission of the planned outer European amounts in case the omission means also omission of the amounts. Since the demand increases, the prices increase which makes the import of more outer European natural gas possible. Further, an increase of the transmission capacities is needed to ensure the delivery of gas. In case of an omission, the planning and procurement of gas will change. Therefore, this analysis shows only the case of a decrease of LTC amounts and the outcome for the inner European countries. Nevertheless, the two results derive: the need of more transmission capacity and production.

The influence of liquefied natural gas

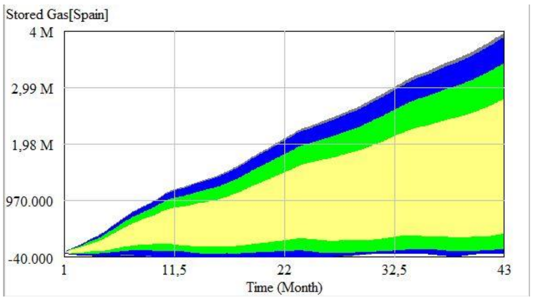


Figure 26. Stored Gas in Spain with more LNG

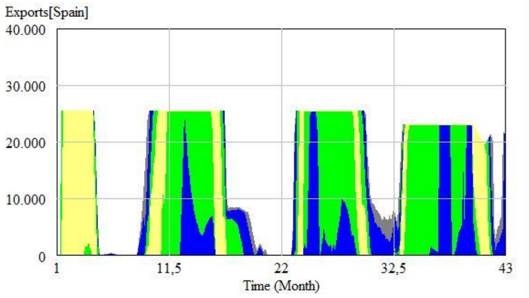


Figure 27. Spain's Export with more LNG

The second scenario is the increase of liquefied natural gas (LNG) capacities and thus import. The increase of LNG was predicted by several studies (Reymond, 2007; Lise, Hobbs, & van Oostvoorn, Natural gas corridors between the EU and its main suppliers: Simulation results with the dynamics GASTALE model, 2008; Kumar, Kwon, Choi, Cho, Lim, & Moon, 2011). Reasons mentioned are the energy content, the security of supply and security of transport. First, the energy content of one m³ of LNG equals 593m³ of natural gas according to IEA. The energy content in combination with the decreasing cost of ship cargo leads to low transportation cost. Further, technological advancements lowered the cost of gasification facilities as well as LNG ports by 20-25% between 1990 and 2000 (Reymond, 2007). Hence, LNG becomes more and more economically attractive. Second, LNG offers the possibility to diversify gas suppliers. Percebois (2006) points out that the diversification of suppliers is one part, aside from price stability, of lowering the vulnerability of insufficient supply security. Thus, using LNG enables member states to import natural gas from countries which are impossible or hard to reach by pipelines like Trinidad and Tobago, Qatar or Malaysia (Reymond, 2007). Last, LNG also has advantages for incumbent suppliers since the transport will be from supplier directly to the member state[8]. So far gas transmission goes through politically unstable countries like Ukraine, Georgia or Belarus. In the Russo-Ukrainian gas dispute of 2006, the Russian government repeatedly accused the Ukraine of stealing gas from the pipelines. Direct ship cargo would eliminate the transportation risk. Thus, it is very likely that the LNG capacity and trade will increase in the coming years. Thus, it is important to examine what is likely to happen with the trade volumes given this scenario. That scenario is done by the implementation of three tuner variables which influence the LNG import and export capacities and the outer EU imports.

The first evident finding is that more gas gets into Europe. However, it is assumed that existing LNG ports are enlarged but no new ports are built in countries that do not possess LNG capacities at the moment. Thus, the focus lies on UK, Belgium, Spain and the Netherlands. But the impact on other countries is interesting. Figure 26 shows the sensitivity analysis of the stock of gas in Spain measured in TJ. It is likely to increase. The next figure is more interesting. It shows that it I likely that Spain’s exports are likely to increase in case of an increase of LNG capacities (see figure 27).

[8] Given the member state has access to the ocean

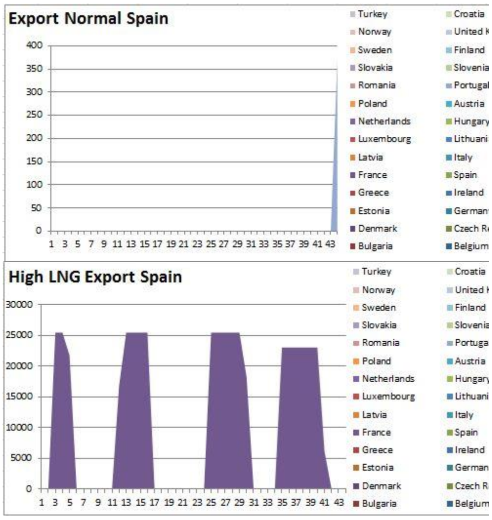


Figure 28. Comparison of trade partners of Spain more LNG

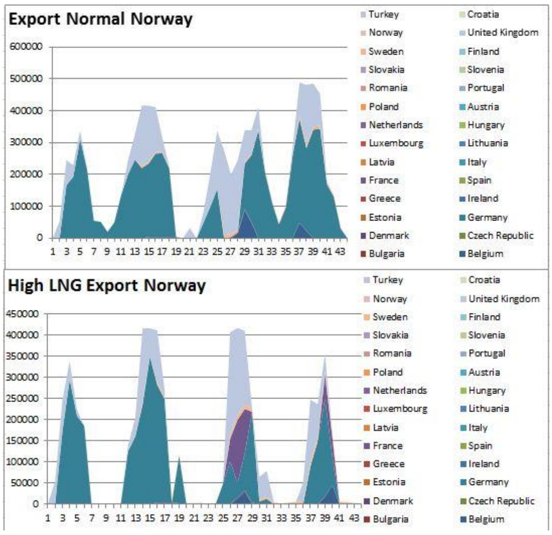


Figure 29. Norway's Export Comparison

The question is then, where do the exports flow? At the moment, the gas flows from Eastern Europe to Spain and Portugal, whereby Spain and Portugal are well supplied by LNG as well. Figure 28 shows the comparison of the normal simulation on the top and the simulation with higher LNG capacities on the bottom of the figure. It can be inferred that not only Spain starts exporting but that Spain is also exporting the additional gas to France. Therefore a flow from Western Europe towards more eastern located countries is observed. Figure 28 is the simulation result of a doubling of the LNG capacities.That will therefore also influence neighboring countries. In the next step, it is therefore interesting to look at countries with no LNG imports. Figure 29 focusses on Norway. Norway is a self-sufficient country and the main supplier to a big part of European countries. The increase of LNG capacities leads to a disadvantage of Norway. As can be seen, the figure at the top (simulation result under normal condition) differs from the lower part (simulation results of the scenario with increased LNG). Both graphs are measured in TJ per month. In the upper graph, exports reach 500000 TJ per month, whereby the increase in LNG leads to exports of only 40000 TJ per month. Consequently, an increase of LNG capacities is not in favor of Norway.

The finding is surprising since the export capacities of Norway were increased as well. However, research shows that LNG is profitable for long distance transportation what is not given in Europe. Figure ***30*** shows an estimation of transportation cost. This scenario revealed an interesting finding. The traditional gas flow through Europe will change under the circumstance of increasing LNG capacities.

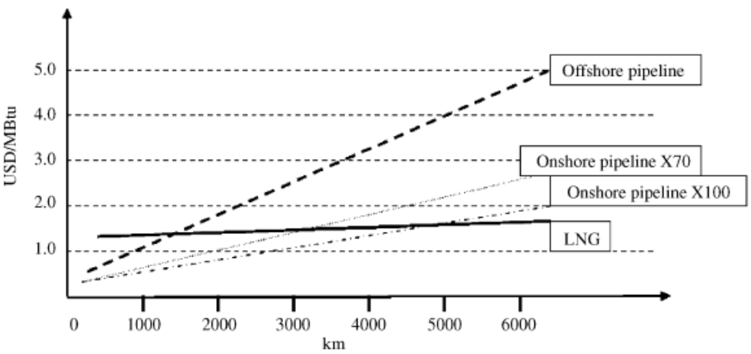


Figure 30. Unit transportation cost by LNG tanker and onshore/offshore pipelines (Reymond, 2007, S. 4173)

The introduction of bi-directional pipelines

The third and last scenario is the introduction of bi-directional pipelines. The European Commission (EC) reported about a lack of investments in the gas infrastructure. For that reason, a budgetary impulse for key projects was suggested. It mentions the change from one-directional into bi-directional pipelines (EU, COM(2010)191). Shortly after this report, the idea was adapted by the blueprint for the future of the EU gas market (EU, 2011a). The idea behind the change is simple: By having the flexibility of changing the direction of the gas flow, the capacity for either import or export is increased. However, it will be on the cost of the opposite flow which makes the impact on the inner European trade hardly predictable. Hence, the simulation will shed light on the impact of the introduction of bi-directional pipelines.

The implementation of this scenario into the model is done by implementing only one capacity of pipelines, i.e. the sum of import and export capacity of pipelines is built. Then, a decision rule for the usage of pipelines needs to be chosen. It is more logical to decide on the import of natural gas first and derive from that need the available capacity for exports. Simply put, if more import is needed, export capacity is going down. If the desired import decreases, more export capacity is available.

Figure 31 shows the simulation comparison of Germany's imports measured in TJ per month. The blue line is the simulation with bi-directional pipelines. The red line is the normal run. It can be inferred from the figure, that Germany has higher imports. Especially at the end of the simulation period, we can see that the blue line exceeds the red one. Figure 32 shows Germany's exports. Again, the blue line is the scenario run, the red line the base run. The blue line has more peaks and the frequency of the peaks is higher. That means that Germany's exports become more flexible. In general, the blue peaks are also higher than the red curve. That proves the re-allocation of the capacity

In order to underline the gain in flexibility, figure 33 compares the imports (red line) and exports (blue line) of Denmark measured in TJ per month. First, the blue line is limited by the capacity but goes down as imports increase. Again, the frequency of the peaks is high and it shows that the

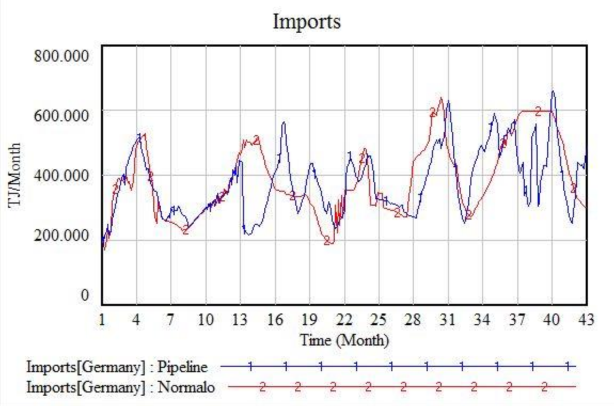


Figure 31. Germany's Imports with Bi-Flows

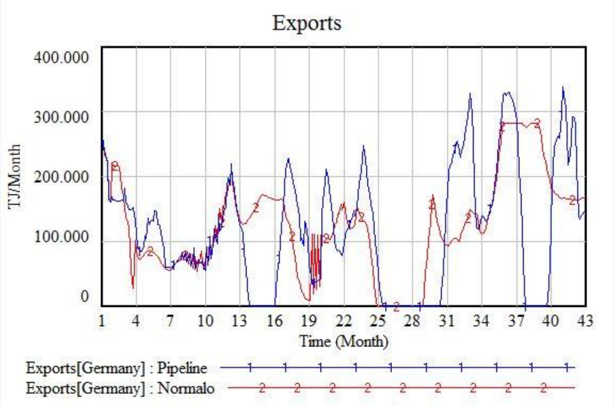


Figure 32. Germany's Exports with Bi-Flows

flexibility of imports and exports is higher than in the run before.

In conclusion, the implementation of bi-flows increases the flexibility of the system. The model shows that the import and exports are less seasonality based and also the increase of imports and exports in the different seasons. However, that is the case under the assumption of flexible capacity allocation.

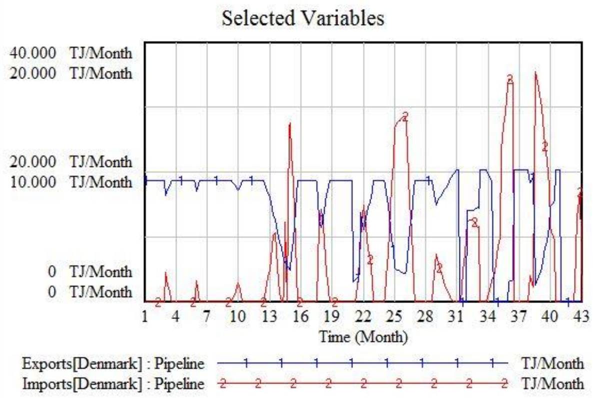


Figure 33. Denmark's Imports and Exports

Discussion

The model which was developed for this thesis has surely some shortcomings. It does not focus on capacities or quality of gas. Further, there is no link to other alternative fuels. Due to externally fed in data, stocks can go negative and only neighboring countries can trade with each other, even though data shows that this is not the case. Moreover, the reference mode reproduction is less sophisticated but the model is useful. It appeared to be helpful for several reasons. The modeling process revealed major data flaws of Eurostat. The model also showed that gas storages are not used strategically. With a simple TREND function of the external consumption data, the imports could be generated. That means that countries still import when demand is highest. The idea of buying gas in the summer to store it for the winter is not given. The data used for the model proves that.

Further, the two criteria – price and availability – play indeed an important role in the choice of the trade partner. However, they are not the only criteria. The dynamic hypothesis that these criteria lead to a preferred supplier and the capacity allocation is done by a priority measure is a nice feature but surely not enough to replicate the inner European gas market. The question is also if LTC exist within Europe and how many decisions are politically driven.

The analysis of the model showed that accuracy is not given but the model shows the flow of gas from one country to another – passing neighboring countries if needed. The model behaves consequential in extreme conditions and revealed some surprising facts in the scenario analysis

In the scenario of the omission of LTC, the model revealed the lack of capacity and the need for higher production. Since the sudden omission of LTC brings along a lack of outer European gas imports. However, the increased demand will lead to an increase in prices and thus, there will be new ways of import. The model was not built to simulate new decision rules: It can therefore only be used for the prediction of a possible trend at the moment LTC are omitted.

The scenario of an increase of LNG capacities showed that more gas will come to Europe which will lead to more trade and that the traditional gas flow direction from east to west is not apparent in the scenario. It also shows that the LNG export within Europe has only little effect. It is likely that the prices decrease due to the increased amounts of gas. Further, LNG will be a competitor of the incumbent natural gas producer in Europe. The model does not take into account decreasing transportation prices or innovation like pipeline LNG transport. Therefore, given all other things stay stable and LNG capacities increase, the scenario presents a possible trend of the market. If the assumptions do not hold, the market will develop differently.

In the last scenario, the implementation of bi-directional gas pipelines was examined. The scenario showed that the flexibility of the gas network will increase due to the increased capacities. It shows that in need more gas can be imported. The biggest advantage is given for producing countries since they can flexibly decide on how to best allocate the capacities. The underlying assumption is that the allocation of the capacities can be done simultaneously. That is a strong assumption since at the moment the allocation is done by auctions. Once a company obtained the capacities bought, it can decide on using it or not. An apparent problem is how fast these unused capacities can be sold. Consequently, the bi-flow structure leads only to an increase in flexibility when the planning process is flexible as well.

From a technical side of view, the model demonstrates how several market players can interact simultaneously and how “the market” is actually created by the interaction of several different actors. In that way the model became complex but with the feature of excel based data input still flexible enough to feed in new data, related information or to change the model to analyze related goods like water, oil or electricity.

Nevertheless, the findings are to be criticized since the assumptions were strong. Further research is needed to integrate this model into models that focus on investment decisions, gas reserve depletion, capacity increase and technological development. In that way the model would on the one hand grow but on the other hand be useful to complete a model of the inner European gas market. However, a premise of SD is not to model the system but a problem. This model might have already reached the border between modeling the system and the problem.

Conclusion

Within the context of this thesis, the European gas market was analyzed. The liberalization process was summarized and the existing models were explained. It was found, that no model combined the current stage of the liberalization process, realistic assumptions and a dynamic approach. That is why a system dynamics model was built. The aim was to develop a flexible model of the inner European gas market in order to analyze three scenarios.

The model grounds on the assumption that the price and the availability of gas are the main factors of a country to choose a supplier. The trade relation between the demanding and supplying country defines the allocation of the scarce good and available transmission capacities. The derived model performed mediocre in adequately reproduce the reference modes but was proven consequential and logical in its behavior. It was found good enough to analyze (1) the omission of long term contracts, (2) the increase of LNG capacities and (3) the implementation of bi-directional pipelines.

The model revealed that in case of the omission of long term contracts, production and transmission capacities need to increase to close the gap of demand and supply of several countries. The prices increase as well an increase of LNG capacities leads to more gas within Europe and more trade. The gas will also be traded from west to east. The prices stay stable or decrease. LNG imports are increased competition for European gas producer. The increase of LNG export capacities does not play an important role for the inner European trade. In the case of bi-directional pipelines, the model showed increased flexibility for natural gas producing countries. There is also a little effect on non-producing countries. Flexibility means the switch of capacities between import and exports. In the scenario it was shown that the imports are then less seasonality driven.

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