Stochastic Optimization of Natural Gas Portfolios

U. Padberg, H.-J. Haubrich

RWTH Aachen University
Institute for Power Systems and Power Economics
Schinkelstraße 6, D-52056 Aachen, Germany
Tel.: +49241-8097692
Fax: +49241-8097197
Email: up@iaew.rwth-aachen.de
URL: www.iaew.rwth-aachen.de

Abstract

Within the next years a significant increase of the demand for natural gas is expected due to the increasing attraction of electricity generation in gas fired plants with comparatively low greenhouse gas emissions and an ascending in household consumption. Additionally, for commercial enterprises of the natural gas sector, new opportunities to acquire new customers and risks to lose existing customers to competitors emerge from the liberalization of the natural gas market. Hence, a rising cost pressure caused by the intensifying competition is expected. Under these circumstances the optimization of natural gas portfolios of commercial enterprises becomes more important.

The optimization of a natural gas portfolio has to be carried out considering uncertainties. For example the demand for natural gas depends strongly on the outdoor temperature and the gas prices might be influenced by politics or may rise due to aggravating production conditions.

Therefore, the objective of this work is the development of an optimization method to calculate a profit-maximizing natural gas portfolio under consideration of planning uncertainties and technical restrictions.

Keywords

Natural gas portfolio optimization, commercial enterprise, stock exchanges, network access, storage access
1 Introduction

In the near future, a significant increase of the demand for natural gas is expected: The electricity generation in gas fired plants becomes more attractive because of comparatively low greenhouse gas emissions. Additionally, the number of households and small consumers using natural gas for heating is increasing.

In addition, the liberalization of the natural gas market offers customers the possibility to choose their supplier. For that reason, a price competition is developing between commercial enterprises in the natural gas sector: One the one hand these enterprises have the chance to acquire new customers, on the other hand the risk of losing customers to a competitor emerges.

The rising demand and the emerging price competition force commercial enterprises in the natural gas supply sector to procure the gas demand at the most favorable price. The procurement planning for the demand for natural gas can only be realized considering uncertainties and technical restrictions.

The uncertainties, like the outdoor temperature and political decisions or production conditions affect the demand and the prices for natural gas.

Technical restrictions affect the transportation capacity of the natural gas pipeline system, the natural gas storage capacity and the fill-level-dependent injection and extraction rate of natural gas storages.

Therefore, the objective of this work is the development of an optimization method to calculate a profit-maximizing natural gas portfolio under consideration of planning uncertainties and technical restrictions.

2 System overview

The considered system is shown in fig. 1. The focus of this work are commercial enterprises of the natural gas sector that supply end customers, industrial facilities or power plants. These enterprises may obtain natural gas directly from a natural gas deposit or buy it directly from a natural gas
producer. Natural gas can also be purchased from other commercial enterprises. Other possibilities to buy or sell natural gas are stock exchanges which operate in several European countries. The natural gas has to be transported in a gaseous state in pipeline networks or in a liquid state as Liquefied Natural Gas (LNG) via ship to the end customer. The uncertainties to be considered are the temperature which influences the demand and the natural gas prices at stock exchanges. Network or storage access contracts as well as delivery contracts may be interrupted. The end customer in general has a strong temperature-dependent demand for natural gas due to the main usage of natural gas for heating (48%). The industrial sector contributes 25 %, non energetic consumption 14 % and electricity generation 13 % [23]. In the following, the results of the analysis and the conclusions for modeling them for the method to be implemented will be presented.

![System overview](image)

**Fig. 1 System overview**
The considered time horizon is a financial gas year (1 October – 30 September, in Austria 1 January – 31 December [11]). As the main time unit in the natural gas sector is the gas day, the considered time pattern will be one day. However, as contracts with demand rates inferior to a gas day become more important, the time pattern will be flexible and can be chosen by the user to one day or one hour.

3 Analysis of the components

3.1 Natural gas deposits

Natural gas is extracted from underground deposits. It is a natural resource whose quality depends upon the calorific value that varies for every natural gas deposit. In Germany, natural gas of two is generally defined by two different qualities: H-Gas with a high calorific value and L-Gas with a low calorific value. H-Gas cannot be used in a system that is operated with L-Gas and vice versa. So two different networks exist in Germany that have to be operated separately. However, it is possible to reduce the calorific value of H-Gas by adding L-Gas or compressed air to H-Gas and to rise the calorific value of L-Gas by adding higher hydrocarbons like butane or propane [13].

The main part of the natural gas is imported from foreign countries. The major share of natural gas imports originate from Russia (34 %), Norway (25 %) and the Netherlands (20 %). Domestic production covers about 15 % of the consumption; the main part of the German deposits can be found in Lower Saxony [1]. In the method to be developed, a distinction has to be made between natural gas deposits far away from the end customer and deposits that are relatively close to consumption because of the relatively low flow speed of the natural gas in a pipeline system. Indigenous natural gas deposits can produce the natural gas in a very flexible way (Swing-Production) in order to follow the exact demand. In some cases, it is even possible to insert natural gas into a deposit.

The production of natural gas in distant deposits is often very const-intensive due to hard production conditions like extreme cold. Furthermore, the installation of the pipelines or of LNG-terminals to deliver the gas to the end customers is very cost intensive. To hedge these high investment costs, natural gas producers are only interested in offering take-or-pay-contracts with a relatively
constant, specified quantity of natural gas to be delivered for a long contract period of about 20 years. Contracts with natural gas producers typically contain flexibility in production. Ingenious producers offer in general a higher flexibility between the delivered quantity of gas in summer and in winter time (120% – 150%) than distant producers (110% – 120%) [4]. For that reason, this type of natural gas deposit can be modeled dependent from the distance to the end customer and the offered flexibility as a natural gas storage or a take-or-pay delivery contract (see below).

3.2 Transportation

Natural gas is generally transported in a pipeline-system from the producer to the end customer. The grid gas is transported in transport networks using pressures from 1 bar up to 100 bar (high pressure) above the atmospheric surrounding pressure. The end customer is generally supplied by a distribution network using medium (0.1 – 1 bar) or low (< 0.1 bar) pressure. However, larger customers like industrial facilities may also be supplied by a high pressure access to the network. If the natural gas deposit is located for example on another continent, but not too far away from the sea, it might be economically reasonable to liquefy the natural gas and transport it by ship. The gas is liquefied by cooling it down to -160 °C at atmospheric pressure. The volume of the natural gas is reduced by a factor of 600. Because of the high losses in liquefaction and the high installation costs of LNG terminals, a LNG transport becomes economically reasonable above distances of 4,000 km between deposit and customer [15], [16]. The LNG is vaporized and inserted in the normal pipeline system when the LNG-ship reaches its destination. The origin of the natural gas – from a deposit connected by a pipeline system or from a LNG terminal – is not important for a commercial enterprise as the physical transport of the gas is the task of a network operator. The commercial enterprises procures the gas by signing a delivery contract with another company. So the LNG transportation itself has not to be modeled in the method.

The access to the network is governmentally regulated, so the commercial enterprises have to book access to the network by contracting entry- and exit-point-capacities [5]. In addition, an accounting grid contract has to be signed in order to constitute the simultaneous injection and extraction of natural gas from the pipeline system. The fees that have to be paid for the network access depend strongly on
the period and time of the booking. In general, the fees in winter time are significantly higher than in summer time. The network fees have to be considered and will be approximated in the method to be developed by a linear function.

As the technical part of the natural gas transport is the task of the network operator, the physical transportation process will not be considered in the method. However, technical restrictions like a maximum entry- or exit-point capacity have to be considered as boundary conditions for the optimization problem. These capacities vary over time and can be modeled by time series. As the entry- and exit capacities are limited, sometimes they even avoid trading operations [19].

3.3 Natural gas storages

Natural gas storages are essential for a reliably natural gas supply in Germany. Several types of storages can be distinguished by their capacity and their technical behavior. The most important storages types are underground seasonal storages. The storages are filled during periods of low demand and depleted during periods of high demand. The pressure in these storages can reach 220 bar.

The largest underground natural gas storages are pore-space or aquifer storages. The largest natural gas storage in Europe is located in Germany (Rehden) and offers a volume of more than 4 billion m$^3$ [22]. These storages are build in porous rock formations. Depleted natural gas deposits (or even not depleted ones) can also be used as a pore-space storages. Because of their high capacity, these storages are used for a seasonal balancing of the demand for natural gas.

Cavern storages are located in underground cavities in sold rock or salt deposits. They are in general smaller than pore-space storages but have higher injection and extraction rates. For that reason, cavern storages can not only be used for seasonal balancing but also to cover peak loads or as trading gas storages that are filled at times with a low natural gas price level at a stock exchange in order to sell the stored gas at a time with a high price level.

LNG storages are used to cover extreme peak loads, for example at extremely cold winter days. Compared to cavern or pore-space storages, the volume is quite small. They offer a very big extraction
rate, but the injection rate is very small. Refilling of a LNG storage may afford more than six months [4], [12].

In order to balance daily load fluctuations, smaller storages can be used. Natural gas can be stored in tube storages. In this case, an underground tube system is build up and filled with natural gas. The operational pressure is up to 70 bar. The largest tube storage in Europe has a capacity of 700,000 m³ [20]. Tube storages have a send-out period of about 12 h [4].

Another possibility of storing natural gas is rising the pressure in the transportation network itself in times of low demand. By reducing the pressure in times of high demand, the network can be used as a system buffer. Due to the liberalization of the natural gas market, the transportation networks are now under the control of the network operators, so this type of natural gas storage is not longer available for a commercial enterprise and will not be considered in the method.

All other types of storages – including natural gas deposits – have to be considered and can be represented by the technical parameters injection capacity, extraction capacity and storage capacity. For that reason, the same model can be applied.

Technical boundary conditions that have to be considered are a maximum and a minimum fill level of the storage and a maximum and minimum injection and extraction rate. Furthermore, the injection and extraction rates are not constant in general but depend on the fill level. A storage has in general a higher extraction rate if it the current fill level is near to the maximum than if it is nearly depleted, the situation is converse for the injection rate. These dependences can be approximated by linear functions.

The access to the natural gas storages is not governmentally regulated, so a great variability of natural gas storage utilization fees can be observed. The simplest storage access model is the storage package model where a fixed volume is defined as well as a fixed ratio of this volume and an injection and extraction rate. The customer can buy a certain number of packages that guarantee the availability of a certain volume with the corresponding injection and extraction rate capacities. These packages constitute the bundled capacity. Especially in short term storage access trading, only unbundled storage access may be possible. In this case, the volume, the injection and extraction rate can be booked separately.
The fees for a storage package and for unbundled capacity depend on the time and duration of the storage usage, so for the fees also a linear function can be used. They can be linear approximated.

3.4 Delivery contracts

Bilateral delivery contracts between commercial enterprises are the most important element for the natural gas supply in Germany. Contracts with enterprises from other countries are in general long term take-or-pay-contracts. Within Germany, long term delivery contracts between to commercial enterprises are restricted. If the delivered natural gas covers more than 50 % of the customer’s demand, the maximum duration of a delivery contract is limited to four years, if more than 80 % of the customer’s demand are covered, the maximum duration is only two years [3].

In general, two types of delivery contracts can be distinguished: consumption dependent contracts (full-supply contracts) and consumption independent contracts. Hybrid forms of these types are possible.

In a full-supply contract, the delivered quantity of natural gas is equal to the demand. Boundary conditions limiting the delivery to the customer like a maximum delivery rate can exist. Most full-supply contracts comprise two price components: an energy price and a demand rate. The energy price is imposed for the quantity of energy that is sold during the complete period of consideration. The demand rate is charged additionally for the highest consumption within a short time interval (one day or one hour) in the considered period. Both energy price as well as the demand rate may be charged gradually. In this case, a new energy price and / or a new demand rate are applied if the total consumption / the demand within an hour or day exceed a specified quantity [18]. Contracts may define more than one graduation. Full-supply contracts have to be considered in the method. The energy price and the demand rate can be considered by using linear functions and linear boundary conditions. The problem of graduated prices can be solved by approximation of the prices by using a linear function or by setting boundary conditions that do not allow to exceed a user specified quantity of natural gas.
Consumption independent contracts are contracted on a specified delivery profile. For that reason, this type of contracts is not subject to any uncertainties. Consumption independent contracts can be considered in the method either by a reduction of the demand for natural gas if the contracting is certain or by using a Boolean variable that decides if the contract will be accepted or not.

3.5 Stock exchanges

Despite the gas supply from delivery contracts, gas can be purchased or sold at stock exchanges. In Europe, stock exchanges that facilitate the trading of natural gas are the Amsterdam Power Exchange (APX) [1] or the Endex [6], both located in Amsterdam in the Netherlands, the Huberator [8] in Zeebrugge, Belgium or the Intercontinental Exchange (ICE) [9] in London, UK. These stock exchanges offer financial futures products for months, quarters, seasons and financial gas years, and physical short term products like gas delivery for the next working day, the rest of the week, the weekend, the working days of the next week and the remaining days of the current month.

At present there is no natural gas stock exchange in Germany. However, the European Energy Exchange (EEX) in Leipzig already announced that the beginning of natural gas trade at the EEX will start in October 2007 [10]. The German transportation network is divided into 19 different market areas. Each market area contains a virtual trading point. A natural gas trading is only possible at these virtual trading points. Only a physical short term trading is possible. However, the number of market areas will probably be significantly reduced in the future [17]. With a lower number of market areas a higher quantity of natural gas will be traded per market area.

Most of the stock exchanges or trading points are relatively small market places. This lack of liquidity necessitates the modeling of a price elasticity. This represents the fact that commercial enterprises influence the price by trading gas: In this case, the price increases if an enterprise buys natural gas and decreases if natural gas is sold. So a price-sales-function (fig. 2) has to be modeled which leads to a quadratic optimization problem. In cases of high liquidity, the price elasticity can be neglected. In this case the commercial enterprises are price takers and the model simplifies to a linear
model. The price gap between sales on the left side of the price-sales curve and purchases on the right side is called bid-ask-spread.

Boundary conditions are the standardization of the offered products at the stock exchanges.

![Diagram](image.png)

*Fig. 2: price-sales function*

### 3.6 Uncertainties

Uncertainties have to be considered for the demand for natural gas that depends strongly upon the outdoor temperature. The consumption in winter times can be up to six times higher than in summer times [14] and differs strongly depending on the average winter temperature. The outdoor temperature also has an indirect impact on the short term natural gas price: If near the end of the winter the storages are nearly depleted but the outdoor temperature remains low, the short term gas price at stock exchanges rises.

Another uncertainty influencing the price is the general increase of demand for natural gas that exceeds the increase of the natural gas production capacity in Europe. The rising demand causes a shortage of offer. Thus, Europe becomes more and more dependent on natural gas imports from other countries, especially Russia. Additionally, aggravating production conditions emerge if natural gas deposits that are located in inaccessible areas with extreme climatic conditions are developed. The linking of the natural gas price to the oil price might be abolished in the future. This has been observed in the liberalized natural gas market in the UK. Finally, political decisions may influence the gas price, e.g. in the Ukraine at the beginning of 2006 and in Belarus at the beginning of 2007. These uncertainties influence the natural gas price in general in a long term consideration.
Failures of the components of a natural gas supply system also have an impact on the natural gas supply. The failure of a natural gas storage is the most decisive one. It can take several months or even more than a year to restore the original state of the storage [7].

A problem in a transportation or distribution pipeline does not lead automatically to a supply interruption. Statistics for the Dutch gas system show that the reliability is about 60 times higher than for an electrical network. Having a very high reliability, failures of the pipeline network will be neglected in the method.

The uncertainties shall be modeled using the scenario analysis method. In this method, a tree consisting of different scenarios is created. A scenario tree starts with a deterministic root with a probability of 100%. In order to model the uncertainty for the considered time horizon, the scenario tree is branching over time (fig. 3). Each branch represents a discrete realization of the development of the uncertain planning data with a defined probability of occurrence.

![Schematic scenario tree](image)

*Fig. 3: Schematic scenario tree*
The sum of the probability of all branches equals one. The tree structure represents for example a temperature tree that contains branches with low and branches with high temperatures or with a low or a high demand for natural gas. This simultaneous consideration increases the size of the problem significantly compared to a Monte Carlo simulation where a certain quantity of single scenarios is considered. The main advantage of the scenario analysis is that the method delivers determined trading recommendations to the users that are optimal for the whole ensemble of uncertainties. Monte Carlo simulations only offer trading recommendations that are optimal for only one certain scenario.

4 Optimization problem and method

The objective function of the method is the maximization of the contribution margin, which is defined as the difference between the revenues and the variable costs of a natural gas commercial enterprise. The revenues are the payments from the customers to the considered commercial enterprise and revenues from sales of natural gas to other commercial enterprises or at stock exchanges. The variable costs arise from purchases of gas from other commercial enterprises or from stock exchanges as well as the from the utilization fees for natural gas transportation network access and natural gas storage access which depend both on the time and duration of the booking. The objective function is quadratic due to the price-sale function that is necessary in order to consider stock exchanges with low liquidity. For the case that stock exchanges with a high liquidity are considered, the objective function remains linear.

Different types of boundary conditions have to be considered in the method. Technical constraints for natural gas deposits and storages are a maximum and minimum fill level and a fill level dependent maximum and minimum injection and extraction rate. Transportation and distribution network capacities are characterized by a maximum time dependent entry- and exit-point capacity limiting the quantity of gas that can be traded with another enterprise or at a stock exchange. Full-supply delivery contracts can be limited by a minimum or maximum quantity of gas that can be obtained or by a take-or-pay condition. Stock exchanges only offer standardized products. The effect of the standardization of the products is that only certain quantities for certain periods of time (the next
weekend, one month, one season) can be traded. All boundary conditions are linear or can be approximated by (piecewise) linear functions.

5 References

[1] Amsterdam Power Exchange (APX)
http://www.apxgroup.com/
15.03.2007

http://www.erdgasfakten.de/gaspreise/herkunft_des_erdgases
15.03.2007

Statement zum General-Thema „Renaissance der Missbrauchsaufsicht“
13. Handelsblatt Jahrestagung Energiewirtschaft
17.01.2006, Berlin

The European Market for Seasonal Gas Storage,
2005

Das Entry-Exit-System – Was ist zum Gaswirtschaftsjahr 2006/2007 zu tun?
Energiewirtschaftliche Tagesfragen, Band 56 (2006), Heft 9, S. 50 – 51

[6] Endex
http://www.endex.nl
15.03.2007

[7] GASAG Berlin
http://www.gasag.de/de/installateure/energie/erdgasspeicher/index.doc.html
15.03.2007

[8] Huberator
http://www.huberator.com/
15.03.2007

[9] Intercontinental Exchange (ICE)
https://www.theice.com/homepage.jhtml
15.03.2007

[10] Lindgens, P.; Menzel, H.-B.
„Erdgas ist sehr wichtig und könnte das zweite Standbein der EEX werden“
e/m/w 2006, Heft 5, S. 60 – 61

Gas und Strom – Immer noch ein Widerspruch?
Energiewirtschaft, 106. Jahrgang 2007, Heft 6, S. 18 – 20


[17] Schroer, P. M. Bald nur noch zwei Marktgebiete? e/m/w 2007, Heft 1, S. 22 – 24


[22] Wingas http://www.wingas.de/sp_speicher_rehden.html?&L=0 15.03.2007