

DK 970 1603

NEI-DK - - 2668

ENERGIFORSKNINGSPROGRAM 95

Gas Storage - Estimation of the economic value

- the English extracts

May 1997

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RAMBOLL

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14. PROJECT DESCRIPTION

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The contribution of RISØ is found in the main reports, Chapters 7, 8 and 9, which primarily concern a socio-economic establishment of values of the expansion of natural gas storage in Denmark, assuming an ideal gas storage strategy.

1. Summary, conclusions and recommendations

1.1 Reading directions to the main report

In order to ensure that readers of the present report achieve the maximum benefit of the selected broadness and theoretically varied interpretation and analyses, two suggestions for basic reading directions are made.

1. Introductory and quick interpretation of the report and conclusions

Project description to the Danish Energy Agency, the basis of the project, has been recapitulated in Chapter 14.

The report has been summarised in Sections 1.2 through 1.4. A general introduction of the project, the subject "gas storages" and the selected method, has been made in Chapter 2.

The natural gas in Europe is described in Sections 3.1 and 3.2. The Danish gas consumption and system have been described in detail in Chapter 4. (Not included in these English extracts)

Chapter 6 in its entirety is about the alternatives to gas storage investigated in the report. Finally, all the alternatives are summarised and classified in Section 6.8. (Not included in these English extracts)

2. Specific subjects, analytical elaboration and focusing

Forecasts and politics

Chapter 5 describes the future role of natural gas focusing on the new Danish energy plan "Energy 21" and the latest analyses from the EU. The liberalisation of the gas market and the latest proposal for directives on the liberalisation have been dealt with in Section 3.4. Finally, the environmental impacts of gas storages are assessed and quantified in Chapter 10. (Not included in these English extracts)

Prices

Sections 4.5 and 4.6 describe the Danish prices on natural gas and their demand elasticity. The possibilities and consequences of cost determined tariffs and variable taxes are dealt with in Section 6.7. (Not included in these English extracts)

Models and analyses

A simple model describes the gas storage benefits in Section 4.7. A comprehensive dynamic socio-economic optimisation model is introduced in Chapter 7. It is described further and the results obtained are available in Chapter 8. The scenarios listed and analysed are described in detail in Chapter 9. Finally, the liberalised American market has been statistically analysed in Chapter 11 in order to estimate the market-related value of gas storages. (Not included in these English extracts)

3. Additional reports

Parts of the report are based on the additional reports:

- Changed tariff and tax structures
- Dimensions and costs of alternative gas connections
- Analysis of the American gas market
- Gas contracts

1.2 Summary and conclusions

Chapter 2 introduces the project "Gas storages - Estimation of the economic value". The project and the report are based on the socio-economic evaluation of the value of gas storages. Hence, no investigation/calculation has been made of the company financial side of gas storages. Many alternatives to gas storages have been evaluated, so that the spectre of possibilities available instead of gas storages has been applied indirectly to give an estimate of the value of gas storage.

11 new pipelines have been investigated as alternatives - in some cases combined with a new production capacity, LNG facilities, differentiated tariffs, conversion of decentralised power plants and interruptible clients.

In order to establish a perspective in terms of a market the analysis further comprises a value of storage services abroad and a market example from the USA. Finally, several theoretical considerations and models, and a larger dynamic socio-economic model calculating the value of new possible storage extensions, have been applied.

In Section 2.2 a description of the various possibilities of application of a gas storage has been made. *Seasonal storage* to smoothen the large variations in consumption from summer to winter. *Security of supply storage* making sure that the supply can be continued in spite of technical (maintenance, repairs and incidents), commercial or political interruptions of the gas supply. Finally, the storage may be controlled by *economic optimisation*, i.e. buying gas when it is cheapest and selling when it is expensive. The chapter is finalised with a description of the different types of storages, including aquifer storages, cavern storage and LNG storage.

Chapter 3 contain a description of the role of natural gas in Europe. Through a general description of technical, production, storage and consumption conditions, the position of Denmark amongst its European neighbours is presented. Further, a short description of the natural gas sector in the 7 countries assumed to be the most comparable to Denmark is made.

The gas supply to Europe is a combination of own production in the European countries and import from Russia and Algeria in particular. An additional small import of LNG from Libya, Abu Dhabi and Australia takes place. If a balance is made of own production per capita, Denmark joins company with major producers in Europe in 5th place.

In nearly all EU Member States the share of natural gas in the energy market is on the rise. The share of natural gas within the EU is expected to increase from today's approx. 19% to approx. 26% in year 2010. In Section 3.3 is given an evaluation of the supply situation in general - a comparison of Denmark with other European countries. If the consumption per capita is assessed, Denmark comes 14th in Europe.

In Section 3.4 different EU initiatives within the areas of energy, natural gas and liberalisation are described and analysed. The overall EU policy is described and the latest proposal for a directive on the liberalisation of natural gas sector is examined with special emphasis on the paragraphs concerning storage of natural gas. Finally, the European Energy Charter is described.

Chapter 4 contains a description of the role of the natural gas in Denmark, including consumption, supply, infrastructure (pipelines and storages), security of supply as well as the need for storage.

In 1995 the natural gas consumption in Denmark was 3.0 Gm³ and constituted 15.8% of the primary energy supply. The ratio between the maximum monthly consumption in winter and summer is approx. 3.8. Hence almost 4 times as much natural gas is consumed in the coldest month of the heating season as compared to the summer. For comparison the ratio for electricity is merely 1.4. This shows that the gas consumption is significantly more seasonal.

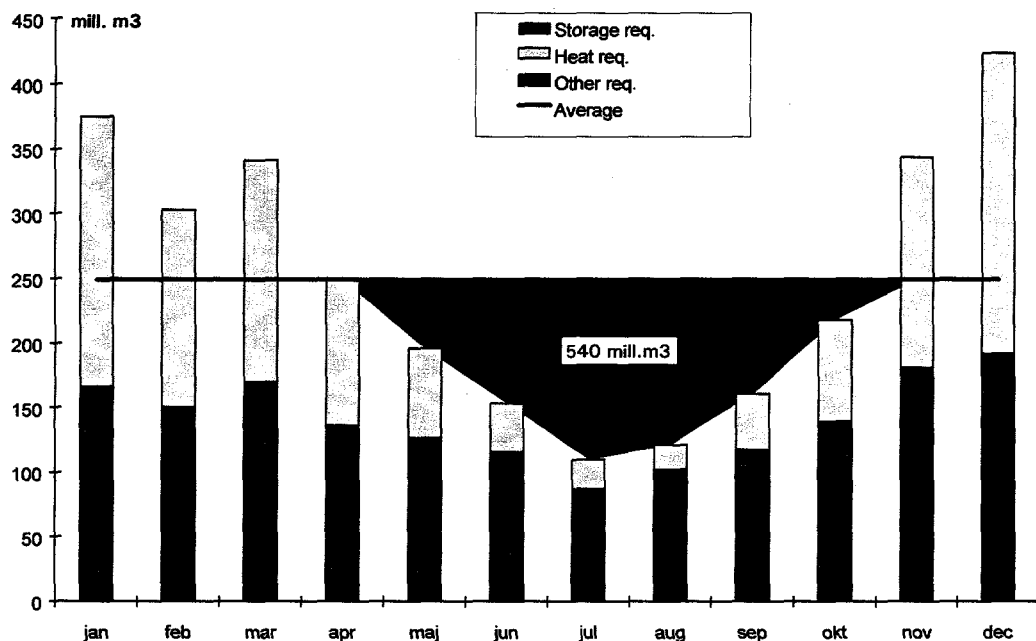


Figure 1.1, Danish storage requirements 1995 - simple calculation

In particular heating related customers have seasonal variations. Single family houses have a 7.3 higher winter consumption, and district heating customers (including

decentralised combined heat and power plants) have a 6.4 times higher winter consumption.

A simple Danish storage requirement has been calculated to 540 Mm³ covering seasonal variations for interruptible customers in 1995 (cf. Fig. 1.1). The forecasts for 2005 in natural gas consumption made by KOMGAS have been used, and they imply a simple Danish need of 740 Mm³.

Section 4.4 emphasises security of supply. Overall, this is to ensure that the customers receive the gas in spite of production fall-out, repairs or accidents with pipelines, etc. Dansk Naturgas A/S (DANGAS) has put forward two objectives for security of supply; one safeguards a short-term period with extremely low temperatures, and one safeguards a long-term period during a longer lasting emergency at normal temperatures. A quantification of the two objectives put forward by DANGAS regarding security of supply, including deference to seasonal variation, results in a storage requirement for 1995 of 750 Mm³, increasing to 1,200 Mm³ in 2005.

The requirements for storage volume cannot be met today with a total Danish volume of only approx. 600 Mm³.

As shown earlier the gas consumption in Denmark is very temperature-dependent. The Danish daily gas consumption has hence been investigated for dependence on the average temperature of the corresponding day. In 1995 at 0°C on Wednesdays and Sundays the average daily consumption was 12.8 Mm³ and 11.1 Mm³ respectively.

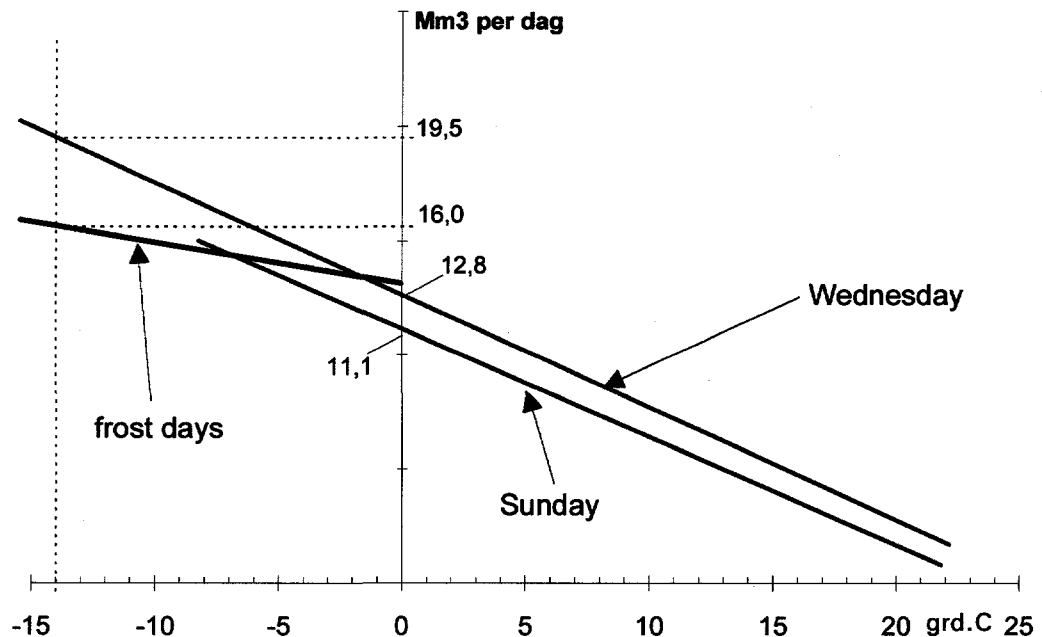


Figure 1.2. Temperature dependence of natural gas consumption

A linear estimate indicated an increase in consumption of approx. 480,000 m³ at a decrease of each degree in temperature. The gas consumption at -14°C, with the linear estimate, is 19.5 Mm³ per day.

In the graphic depiction of the gas consumption and temperature, a 'hockey effect' becomes apparent - the curve bends (shown in Fig. 1.2 as 'frost days'). An upper limit exists of how much more gas is consumed at decreasing temperatures. The gas consumption at -14°C, with the 'hockey curve', is 16 Mm³ per day. In addition, there is an estimated applied capacity in the total export to Germany and Sweden of approx. 6 Mm³ per day.

In this context, it should be mentioned that the existing gas supply locations, Nybro, Ll. Torup and Stenlille, together can supply 42 Mm³ per day. The withdrawal capacity is thus not a bottleneck in the present system under normal operation conditions.

In order to show the sensitivity of the natural gas consumption of the heating market it has been investigated how storage requirements change as a result of the progress selected in the energy plans "Energy 21" and "Danish Energy Futures". It has been calculated how a reduction in energy consumption for space heating in 2005 of 17% and 53% respectively, as compared to 1995, changes the simple storage requirement from the previously indicated 740 Mm³ of gas to 650 Mm³ and 480 Mm³ respectively. In this calculation no consideration to additional consumption in combined heat and power plants has been made.

The Danish price for natural gas has been dealt with at the end of Chapter 4 together with an overall introduction of the valid price elasticity for natural gas.

Finally, a simplified model is introduced indicating the magnitude of the value of gas storages by a simple substitution with other fuels. The socio-economic cost of not having gas storages has been calculated to 0.24 DKK/m³ gas for fuel oil as substitute and 0.88 DKK/m³ gas for gas oil. The differentiation between fuel oil and gas oil is valid for the customers presumed to be substituted. Thus fuel oil covers large industrial users and power plants. The substitution of gas oil is presumed to cover industrial clients and combined heat and power plants.

In Chapter 5 the future role of the natural gas is described. As point of departure assumptions and scenarios from the "Energy 21" by The Ministry of Energy and Environment and the "European Energy to 2020" by the EU Commission have been described and compared.

Several assumptions have been made in both publications which do not coincide, and it is precisely these assumptions which gives natural gas and hence gas storages a bigger role in the future. Both prognoses have been used as input for the dynamic model presented in Chapters 6 through 8.

The differences in assumptions, reference is made to Section 5.3, are reflected in the forecast for natural gas consumption in Denmark shown overleaf.

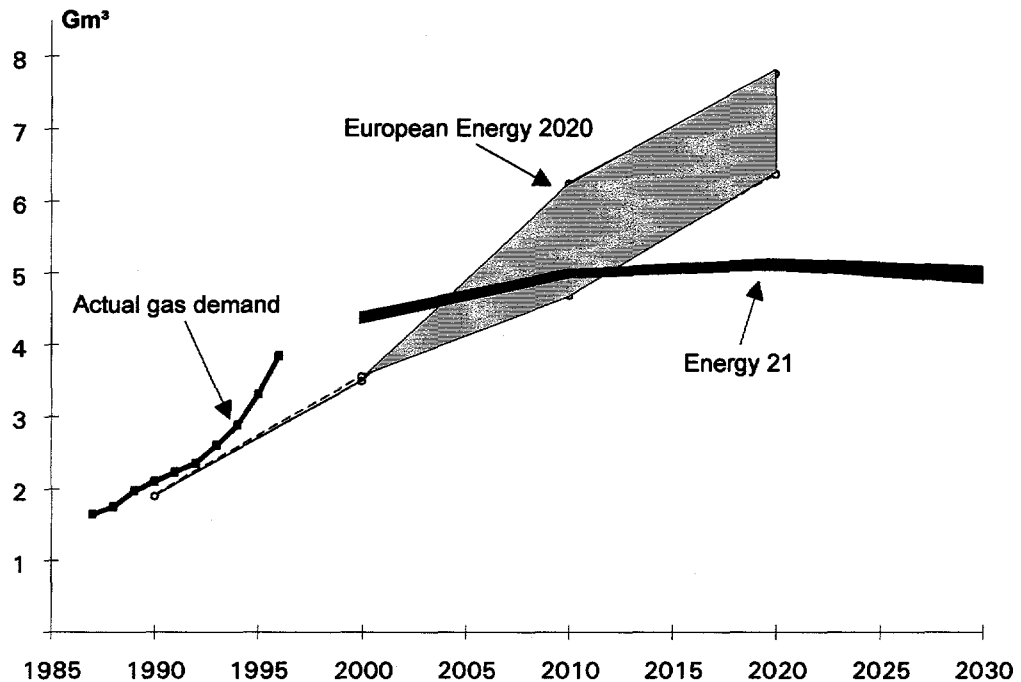


Figure 1.3, Natural gas consumption in Denmark 1985-2030

Chapter 6 contains a description of alternatives to gas storages with a view to determining the value of new gas storages. This includes a.o. changed consumption in the decentralised combined heat and power plants, the establishment of new infrastructure to the North Sea or other gas suppliers, LNG facilities, storage service capacity abroad or the application of price mechanisms.

An operational consideration of all alternatives has been made in order to calculate the economic benefits from using the pipeline only during the 3 coldest winter months. This method results in a directly comparable value with a possible (not evaluated/calculated) working expenses for a seasonal storage.

Decentralised combined heat and power plants

The largest of the decentralised combined heat and power plants, with an electricity output in excess of 30 MW, could be transformed to work on oil during the 3 coldest winter months for a natural gas equivalent of 0.70 DKK/m³. The cost on which the calculation is based is for the readjustment of the gas burners. The biggest transformation required for making this decentralised idea possible is, however, that the legislation regarding the 7-øre subsidy is changed, allowing for oil burners to be used for 3 months every year (in peak load/emergency load situations).

Pipelines

11 specific new pipeline connections have been investigated in the report. Overleaf are the 11 alternatives shown. The pertinent economic costs depend on whether the pipelines are onshore or offshore, volume and length. The investment per m³ withdrawal capacity has been found to vary from 84 to 361 DKK/m³/day.

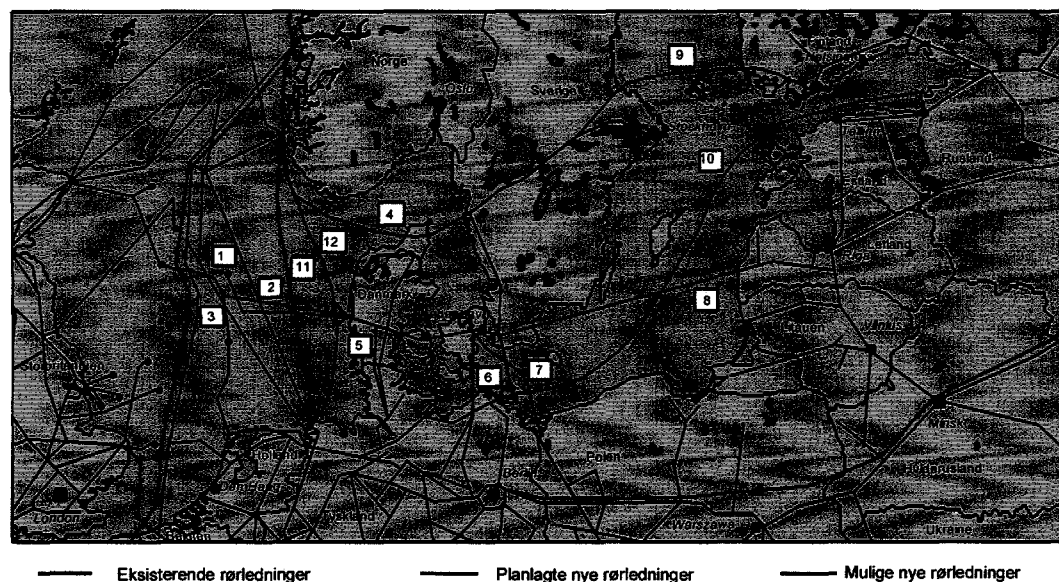


Figure 1.4, Pipeline alternatives.

For each pipeline alternative the excess 'price' of the natural gas has been observed prior to application of the alternative. How much would the gas cost through production, transmission and possible storage before reaching the point of departure of the alternative. Further, the actual capital and working expenses for the alternative are added. The storage equivalent working expenses thus reached for the technical pipeline alternatives have been found to be in the interval 0.39-0.67 DKK/m³. The cheapest alternatives are in this consideration from the North Sea.

LNG storage

With LNG alternatives it is possible to gain direct access to the world market of natural gas and thus become more independent of the neighbouring countries. LNG, however, is a very expensive and energy demanding form of natural gas. An LNG import facility, able to deliver natural gas during the entire winter period (3 months), has a storage-equivalent cost of 0.75 DKK/m³. An LNG own production plant, which can deliver natural gas for 1-6 days with extremely low temperatures, has a storage-equivalent cost of 0.99 DKK/m³.

Services for storage capacity

Storage capacity services abroad have been investigated. The possibility of tendering for storage capacity and volume abroad is, however, still quite limited as there is no free access to the transmission network between user and storage, but in the liberalised market in the United Kingdom there are certain cost determined service possibilities. Service for volume/capacity in a salt cavern corresponding to the total Danish storage requirements (seasonal and security of supply) of 750 Mm³ would in 1996 cost 0.49 DKK/m³.

Having analysed several types of British gas storages (cavern, depleted field and LNG) it must be concluded that Danish market conditions transferred to British price conditions indicate that salt caverns are ideal for large volumes, whilst the LNG option is optimal for covering short-term supplies in peak load or short emergency situations. At the same time a storage requirement corresponding to approx. 1,200 Mm³, the estimated simple need for 2005, should be injected in an empty gas field operated as an offshore storage.

Corresponding to storage equivalent services of 0.73-0.99 DKK/m³ in the United Kingdom, the prices of storage in the Czech Republic and Slovakia is approx. 0.55 DKK/m³. The services themselves, i.e. without transportation to Denmark in the latter countries are estimated to be in the order of 0.20-0.30 DKK/m³.

Differentiated tariff structure

In order to limit the consumption of natural gas in the winter, a general price increase during the winter period which indirectly will decrease the storage requirement also has to be considered. More specifically, the idea of a differentiated price structure has been analysed. The approach could be a reduced summer price, or the gas price could be made cost determined. This would mean that the cost of storing the gas could be imposed on the consumers actually using the gas, i.e. the consumer groups single-family houses and district heating. The last approach is the one applied in the report.

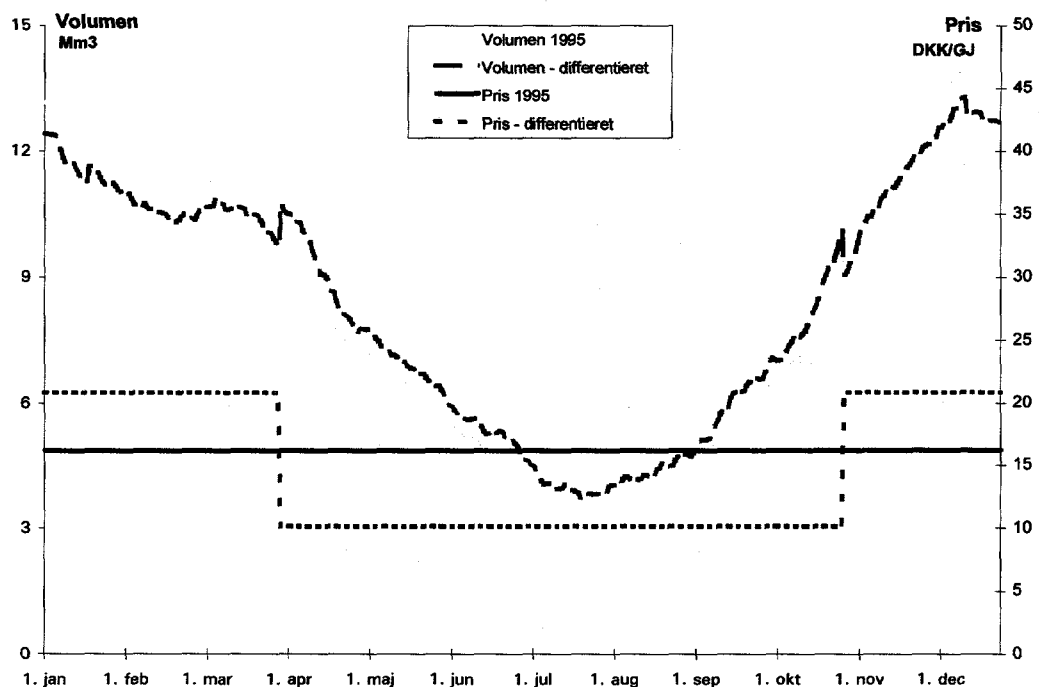


Figure 1.5. Natural gas consumption at differentiated tariffs

With an assumed demand elasticity of -0.20 a reduction in storage requirement of 80 Mm³ is obtained through the introduction of price differentiation, corresponding to the price of the gas stored comprising the total costs of storage. By changing the taxes

further from the present constant to a profit neutral variable, an additional reduction in the storage requirement of 80 Mm³ is attained. Hence a total reduction of storage requirement of 160 Mm³ is obtained through a differentiation of the price structure on natural gas.

Chapter 7 includes a description of the dynamic method and model used for calculating the socio-economic value of gas storage. The optimal operation of gas storages is described and detailed in seasonal storages and security of supply storages. Further, substitution prices of the model are described and quantified.

In Chapter 8 the description of input data and output data is described from the point of view of the dynamic model. The assumptions of the scenario are analysed.

In Chapter 9 the socio-economic value of the dynamic model is analysed and calculated based on data from "Energy 21" and "European Energy to 2020". The conclusions reached are shown in Table 9.1 and described in Section 9.3.

Chapter 10 contains an evaluation of the environmental impact from gas storages primarily in the form of the consequence of energy consumption for injection and withdrawal from the storages. In the summer electricity is used for the compressors injecting the gas into the storage. In the winter (heating period) the withdrawal is expected to take place without any energy consumption as there is overpressure in the storage, but on the other hand natural gas is used for heating/drying the withdrawal gas before sending it through the transmission system.

Storage of natural gas and the pertinent energy consumption, including flaring, increases the CO₂ emission coefficient for stored natural gas by 2.8% from 56.9 to 58.5 kg/GJ.

Chapter 11 comprises a description of the experience in the USA with regard to liberalisation of the gas markets, including the establishment of a market for natural gas. As limit value for the additional technical and business alternatives, this liberalised natural gas market has been analysed. The analysis estimates the market value of storing gas from summer till winter and by having gas stored for unexpected cold/extreme weather conditions

Section 11.2 shows the result of this statistical analysis. The estimates are examined together with the connections found between the listed variables. With a point of departure in data from the winters 91/92 through 95/96 the following results have been obtained:

- **The temperature** influences the possible storage value. In cold weather or unexpected storms the return is 0.11-0.14 DKK/m³.
- The influence of **too little gas in the storages** together with cold weather makes the return of stored gas increase to approx. 0.58 DKK/m³.
- **Time** is an important parameter. If there is a cold spell early on in the heating season, e.g. November or December, the question of whether to withdraw gas

from the storage now, or if the expectation of future cold periods is an invitation to save the gas for later, arises. This behaviour is similar to the problems surrounding the use of peak load LNG facilities. This time dependence is statistically of no significance.

It has furthermore been observed that it is the disparity from normal situations which is the describing parameter. As such, it is the temperature deviation from the normal temperature and the deviation from the normal storage injection, which result in the above-mentioned.

In the graph beneath is shown the American spot price on natural gas together with the weather at the time, measured in American degree days. A clear connection can be seen for the winters 93/94 and 95/96 during which cold weather results in a high spot price. The winter of 95/96 has an all-time high spot price, comprising the value effect of not enough gas having been injected at the beginning of the heating season.

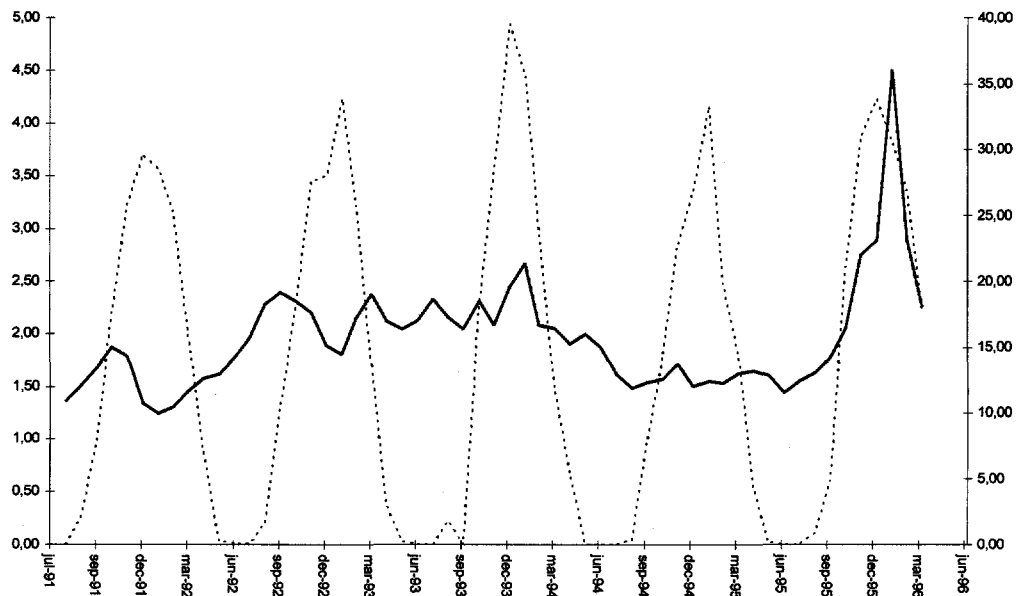


Figure 1.6 , Natural gas spot prices and American degree days (USD/MMBtu : degree days)

An overview of all calculated values of gas storages from the different technical and business alternatives and methods can be shown alongside of the found American market values:

Alternatives	Economic storage equivalent value	
	lower	upper
<u>Alternatives</u>		
- short term (few days)	0,99	1,98
- entire heating period (3 months)	0,39	0,67
- empiri (US analysis)	0,11	0,58
- model (simple)	0,24	0,88
- business (tariffs)	0,02	0,04

Table 1.1, The socio-economic value of gas storages (DKK/m³)

Chapters 12 and 13 finalise the report with an overview of references used and a list of meetings held with the Danish Energy Agency, DANGAS, KOMGAS and the Competition Council, etc.

1.3 Ideas for energy-political measures regarding gas storages

1.3.1 Introduction

The analysis of the economic benefits of gas storages has confirmed the assumption that it is possible to influence the need for gas storages through the energy politics adapted. Likewise, the need for storages - and hence their socio-economic value - can be determined only with great uncertainties with the data available. This in turn is the occasion of some energy-political initiatives which may influence the storage requirements and contribute to an increase in quality of the decision-making process of gas storages. The accomplishment of ideas depends on a political decision-making process.

1.3.2 Ideas for influencing the need for gas storages

Cost-determined prices on natural gas

The application of cost-determined prices in which the costs of storing gas are explicit will influence the need for gas storages. An idea for implementation of this principle could be to change the present rules for pricing enabling the gas companies to make several types of contracts comprising summer discounts, short-term contracts, etc.

Variable taxes for natural gas

The implementation of taxes on natural gas opens for greater political possibilities for influencing storage requirements. Variable taxes on natural gas, e.g. a proportional tax, would, in a continuation of the cost-determined prices, be in a position to determine the need for gas storages. An administratively simple solution could be to introduce summer and winter taxes.

Political targets for security of supply

The use of gas storages for security of supply should be regulated by political implementation of targets for security of supply. In particular with regard to the possibility of more actors in the Danish gas market, the authority should be passed from the gas companies to the politicians.

Increased use of natural gas in combined-cycle plants in the summer

The establishment of a number of large natural gas driven combined heat and power plants based on combined-cycle technique with a very high power output makes it possible to replace coal-based power production in the summer. In particular the connection of decentralised combined heat and power plants to a central combined heat and power area could influence the seasonal profile of natural gas consumption. It should also be considered to equip some plants with cooling.

Oil-fired peak load boilers in decentralised combined heat and power plants

Many small decentralised combined heat and power plants are today equipped with a combination of a natural gas-fired motor and a natural gas-fired peak load boiler. By using an oil-fired peak load boiler instead a more level seasonal profile on the natural gas consumption would result and hence storage requirements would be reduced.

Explicit discontinuation of costs for natural gas storages in the socio-economic evaluations of the Danish Energy Agency

For all energy investments it has been possible to estimate the accompanying need for gas storages, including costs and environmental impacts. This a.o. includes extension plans for oil/gas fields, combined heat and power plants, power plants, renewable energy, tariffs and taxes. Many socio-economic evaluations are based on the assumptions of the Danish Energy Agency regarding fuel prices, which, as regards natural gas, comprise elements of transportation and storage. It is recommended that the storage costs and environmental impacts be explicitly included in the next revision of the calculation assumptions by the Danish Energy Agency.

1.3.3 Better determination of the need for gas storages

Seasonal variations in gas consumption should be evident from the financial statements of the gas companies

Until now Danish gas companies have been in a position to submit the annual sales in their financial statements distributed on different tariffs. In many countries it is traditional to indicate the monthly gas consumption as well as maximum and minimum consumption. Only thus is it possible to estimate the future need of the gas companies for increased capacity, including storage, and with that give a true picture of the economic situation of the companies.

Requirement to long-term forecasts and establishment of common modelling tools

The need for gas storage is extremely dependent on the future development in demand and supply of natural gas, including seasonal variation. The long-term forecast made in Denmark so far, i.e. in connection with Denmark's Energy Futures and "Energy 21", do not include seasonal variation to the extent required, and the models have neither been available to the public nor suited for general use. One idea could be for the authorities, in collaboration with the different supply companies, jointly to prepare a common long-term energy model to be used by the parties applying their own stipulations.

Lack of data

The long awaited opening of the gas markets at present still continues to keep both data and information on gas prices, sales and contractual conditions secretive.

A result from this report on concrete consumption and sales data, with appurtenant prices, should be available to the public on a monthly basis.

A prerequisite for making the present analysis possible, as regards data, is owed to the fact that DANGAS made their 1995 data available.

If the future is anything like that in Norway, the United Kingdom or the USA, to mention a couple of examples, information will flow in unthought of quantities. Electronic bulletin boards, Internet home pages and on-line services in these countries comprise hour-by-hour statements of production (per unit), import/export (per connection), consumption (per consumer groups), etc.

1.4 Suggestions for additional studies

The analysis on the need for gas storages and the determination of the socio-economic value has indicated that there is a need for additional investigations, if a more precise determination of both the need and the value of storages is required.

In particular, there is a need for collection of empirical data on natural gas demand,

and its dependence of temperature, season, prices, etc., and statistical analyses of these data. Additionally, the increased linking of natural gas with the power sector has indicated a need for analysis of the interaction between the water power in the other Nordic countries and the application of natural gas for power and heating production.

The investigation of alternatives to gas storages has indicated that some of the alternatives need further clarification. This is particularly the case of the possible extension of the production capacity in the Danish gas fields in the North Sea, as well as the possibility of using these fields for storage of gas some time in the future. More detailed investigations of some pipeline alternatives have been decided upon by the EU thus including the so-called "Nordic Gas Grid" as a TEN project (Trans European Network). In 1997 a comprehensive study of this alternative will be carried out in a collaboration between 7 Nordic gas companies.

In the following some of the proposals for additional enquiries have been concretised.

Examination of abnormal seasonal variations

Temperature is a significant factor when dimensioning and using storages. A statistical analysis of the average daily temperature over the past 100 years in Denmark would be an important tool in the preparation of a supply policy for extreme weather situations.

A statistical analysis of the connection between cold and dry winters would contribute to an understanding of the possible load to which the entire Nordic power/gas market is exposed.

Correlation with the power sector

The power production in Denmark is increasingly based on natural gas. This justifies the fact that the two sectors, power and gas, are evaluated as one system.

Additionally, a collective Nordic storage evaluation should be carried out which includes the interaction between gas storage and water storage.

Long-term forecasts

The establishment of gas storages is a long process which should be based on valid long-term forecasts. Thus, a proper forecast model should be drawn up focusing on the energy sector.

The use of such a model should include test runs on the preparation of new/changed laws. The consequences in terms of storage could also be calculated based on a given policy.

Price elasticity on gas

An investigation of the reaction of selected consumers to price changes. A pilot project could be established in which, through individual measuring together with data from consumer research project, part of the price elasticity of the gas could be mapped.

Gas storages in depleted fields

Concurrently with the Danish gas fields being depleted, the possibility of establishing offshore storages should be investigated. The work should be based on the possibilities under the valid concession agreements.

Also, the possibility of including the Danish gas fields as commercial storages in a coming liberalised market should be evaluated.

2. Introduction

2.1 Preface

This report comprises the results of the energy research programme "GAS STORAGEES - Estimation of the economic value". The project has been carried out in collaboration between RAMBØLL and RISØ National Research Laboratory under the Energy Research Programme 95.

The target group of this report is the Danish Energy Agency and actors on the Danish gas market. In addition, the results are available in a short version accessible to a wider sphere of people.

The purpose of the project has been:

- to establish/generate an overview of the problems surrounding the economic benefits of gas storages and to illuminate it in as broad a professional analysis as possible
- to supply a concrete description of the European gas system and its development seen from an overall Danish approach, and compare the Danish system with the systems in other
- to present alternatives to gas storages, to collect available information and calculate the economic benefits of these
- to assess/quantify environmental impacts of gas storages
- to shed light on the gas storage problematics
- to carry out estimates of the value of gas storages

A summary of the report as well as conclusions and ideas can be found in Chapter 1.

As part of the project an informative letter regarding the project has been sent to the actors on the gas market and meetings have been held with Dansk Naturgas (DANGAS) and KOMGAS, who both kindly have made information available to the project group. Additionally, informative meetings have been held with the Danish Energy Agency, at which the most significant parts results from the report were presented and discussed. Finally, a meeting with the Competition Council was held, with the Council commenting and evaluating the possible future price and duty structure on natural gas.

2.2 Introduction to the economic method

We have for this report chosen to apply a economic angle for the qualification and quantification of the value of gas storages. The value found will be designated economic value. This comprises the value of gas storages connected to society, and hence no calculation has been made of the company economic side of gas storages.

We have chosen to consider the Danish gas system as a coherent system without taking placing of gas storages into consideration. We hence consider the system one

entity with the possibilities of being supplied from the outside. It is thus not necessary to make a stand regarding concrete proposals for the placing of gas storages.

The calculations in the report conform to the "Generelle forudsætninger for samfundsøkonomiske beregninger" (General assumptions in terms of social calculations). Complete considerations in terms of economic conditions implicate all conditions concerning the society. All advantages and disadvantages. During the work with the report, the factors being the most important in terms of economic value have been assessed continuously, and the factors found are the ones we have concentrated on. Hence, several components of the economic value have not been analysed.

In order to quantify the economic value of gas storages, the many alternatives to storages, which for the society as a whole obtain equal results, are being considered, i.e. that the consumers receive the quantities of energy which they demand. The possibilities lie in giving the consumers all the natural gas they demand, or to give them a corresponding amount of energy or yet to change their demand.

As such alternatives to storages are considered, 11 new pipelines have been investigated, in some cases in combination with new production capacity, LNG facilities, reconversion of decentralised combined heat and power plants, interruptible consumers or the application of price mechanisms. In order to calculate the storage equivalent costs in terms of society for the alternatives mentioned, a broader operational consideration has been applied for each alternative. The alternatives are established with a view to being used only during the 3 coldest months of the heating season. This method enables a directly comparable quantity with a possible (not evaluated/calculated) operational cost for a seasonal gas storage. The fact that we consider the alternatives for a mere 3-month period in a year results in the costs per volume being somewhat higher than if all the qualities of the alternatives were included in the calculation.

The estimated economic benefits have further been put in a theoretical perspective and a perspective in terms of market. Theoretical considerations and models in different ways establish the theoretical value of gas storages and investigations of services of storages abroad, and a large statistical analysis establishes the value in terms of market of gas storages abroad.

2.3 The purpose of gas storages

2.3.1 General

Gas storages are used to displace the supply of gas over time. The most common application of the gas storages is for seasonal adjustments, in particular where consumption, as is the case in Denmark, is very much dependent on the weather, with great variations during the year and from year to year. In case of fluctuating or failing supplies the gas storages may be used to compensate for lacking supplies - *security of supply*. Especially with single pipeline systems, as the Danish, the gas storages play an important role.

Gas storages may also be applied for an economic optimisation in which the gas is bought when cheap and sold when the price is higher. Due to the lack of a European spot market this application has not been developed.

2.3.2 Seasonal adjustment

In principle, seasonal adjustment comprises two elements, i.e. to secure sufficient supply during the winter and to secure sufficient consumption in the summer. This is due to technical capacity limitation of the supply systems (number of wells, pipeline capacity, etc.). It is further desirable, due to economic reasons, to exploit the production and transportation systems all the year round. This is particularly the case for very long transportation systems, such as pipelines from Siberia to e.g. France.

In commercial gas contracts the two limitations manifest themselves in large gas supply contracts containing demands to a certain load factor (the proportion between average and maximum daily supply). The load factor will typically be in the order of magnitude of 0.85 for large transmission systems, but different from contract to contract and typically smaller during the erection phase of the system.

Reference is made to Chapter 13 regarding gas contracts.

2.3.3 Security of supply

Security of supply is an important element in all pipeline combined supply systems. The security of supply can be divided into security against sudden failures of supply and long-lasting interruptions due to technical reasons, but which in principle could have either commercial or political reasons. In case of a short-term interruption of the system, it is in particular withdrawal from the gas storages which is interesting, whilst for a long-term interruption the volume of gas storages is of interest. The physical boundaries further set up limitations as the withdrawal capacity is a decreasing function of the volume.

2.3.4 Economic optimisation

The economic optimisation of the gas supply systems in principle implies that money can be made from buying gas when it is cheap (typically in the summer), and sell it when it is expensive (typically during very cold spells or in case of oil crises, etc.) To illustrate this we have the drastic variations in market prices in the USA during the winter for spot deliveries depending on the present weather situation and volumes on hand. In such a market access to large withdrawal capacities are sought after in order to obtain the highest possible price on the stored gas. Reference is made to Chapter 11 regarding the American market.

As opposed to the oil market there are no restrictions regarding the size of gas storages. Probably because the costs involved when storing gas, which are much higher than those for storing oil, and because natural gas so far has been used in

independent regional markets and hence has been less sensitive to international crises.

2.4 Different types of gas storages

Storage of natural gas can be done in different types of storages. The most common method is the use of **depleted oil or gas fields**. The advantage is the already existing technical installations in connection with the extraction of the resources, e.g. wells and pipeline connections. This type of storage is usually the cheapest, as the investment will be limited to the installation of compressors.

Aquifer storages are storages which are established under a naturally gas-tight membrane by displacement of water. This type of storage requires that larger quantities of gas be injected than can be withdrawn. The so-called cushion gas constitutes a volume which often is twice the amount of the workable volume of gas in the storage. Aquifer storages are typically used for smoothing seasonal variations with injection in the summer and withdrawal in the winter. This type of storage requires large surface installations for drying the gas when withdrawn.

Cavern storages are formed by establishing an actual cavern in solid types of rock, such as e.g. salt domes. In salt domes the caverns are often flushed with water. Also in caverns there is a need for a certain amount of cushion gas, typically the same quantity as the workable gas. Cavern storages can also be established in types of mountains other than salt. Old mine shafts, sealed with a steel membrane, and there are plans of establishing storages in large granite caverns. The advantage of caverns storage is the relatively large capacity of each well, and technically is hence possible to inject and withdraw gas several times during a season.

LNG storages are tank installations filled with cooled natural gas at -160°C . LNG storages are typically used to cover the demand of a large withdrawal capacity or as security of supply in places where the supplies depend on one only unreliable/unstable supplier. The storages can be used as import installations in harbours, but also in the middle of the gas system where the gas is taken from the net, compressed and injected from there.

14. Project description

In the following is indicated the project description approved by the Danish Energy Agency used as basis for the project. And finally, for each heading in the project description the chapters dealing with the subjects in this present report are indicated:

Background

"Energy 2000" with subsequent follow-ups has to a great extent contributed to the increased application of natural gas in Denmark. At the beginning of the 90's this was possible with quite limited investments for transmission and storage of the natural gas due to a certain over-capacity in the Danish natural gas transmission system and in particular the mild winters from 1988 through 1995. During the coming years it must be assumed that the capacity of the present system is exhausted with the subsequent need for investments. In case of severe winters as that of 1986/87 sudden supply problems cannot be excluded.

The rapidly increasing use of natural gas is largely for heating and power production, both dependent on temperature and season. The result is vary large seasonal fluctuations and the ensuing need for gas storages, or alternatively an increase in production and transportation systems (reference is made to the attached figure of monthly gas consumption) in spite of natural gas being the most expensive fuel to store. This contradiction is very much owed to the tax policy applied, with the use of substitution prices for natural gas and constant energy taxes on competing fuels.

Additionally, in Denmark gas storages also have a security of supply aspect as we are the only country within the EU with only one normal connection of supply.

In particular with the underground gas storage projected in Tønder there has been a large public aversion. A similar aversion has been noted in other EU member state countries, especially the Netherlands, where the establishment of a storage has been abandoned.

Determination of the economic benefits

The main purpose of the project is to investigate the economic benefits of underground gas storages used for seasonal smoothing and a strategical security of supply. The benefits from the storages is supposed decided based on the costs of alternative ways of securing the energy supply, including evaluation of i) demand-dependent prices on natural gas and other fuels (both domestic and foreign markets), ii) interruptible supply, iii) establishment of extra production and transportation capacity from the North Sea, iv) establishment of new connecting systems to neighbouring countries (i.a. German, Poland, Latvia), v) establishment for import or production and LNG, vi) contracting of storage capacity abroad (Germany, Czech Republic, Slovakia, Latvia).

Market prices for gas storage

In order to control the estimated costs of storage of natural gas a comparison with market prices for storage capacity and spot prices of natural gas is carried out.

The market prices will be sought determined through a statistical analysis of seasonal variations in gas prices on the American natural gas market (New York stock exchange) due to the lack of a European market. Special emphasis will be put on the severe winter of 1993/94.

Inquiries will be made as to European prices on gas storage services partly through published sources, and partly by contacting the owners of such storages.

Proposal for incorporation of storage costs in energy taxes

Due to constant energy taxes, the energy prices only partially reflect the demand and the price elasticity hence is very small, resulting in a need for e.g. gas storages. One purpose of the project is to investigate this system error and to present alternative suggestions for the tax structure. Additionally, the consequences of differentiating production taxes will be addressed.

EU directives and European Energy Charter

Furthermore, the significance of the Gas Directive proposal from the EU and the European Charter will be addressed.

Increased CO₂ and methane emissions due to the use of storages

The CO₂ leakage for transportation and storage will be decided on based on the various load factors and the origin of the natural gas (Danish sector of the North Sea, Haltenbanken, Russia, LNG). Due to the use of compressors for transportation and storage, the total CO₂ emission for peak load supply is significantly higher than the 56.9 kg/GJ which are usually applied for natural gas in energy planning in Denmark.

Furthermore, the leakage of other greenhouse gases, in particular methane, will be evaluated. Both leaks from surface plants and from the underground storage itself over a long period of time (small leaks over decades or centuries) will be considered.