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Wuppertal Institute for
Climate, Environment,
Energy

Greenhouse Gas Emissions from the Russian Natural Gas Export Pipeline System

Results and Extrapolation of Measurements and Surveys in Russia

FinalReport

**A Project on behalf of
E.ON Ruhrgas AG**

Wuppertal Institute for
Climate, Environment and Energy
in co-operation with
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Project Manager

Stefan Lechtenböhmer

Authors:

Wuppertal Institute
Stefan Lechtenböhmer
Carmen Dienst
Dr. Manfred Fischedick
Thomas Hanke
Thomas Langrock

Max-Planck-Institute
Dr. Sergej S. Assonov
Dr. Carl Brenninkmeijer

With support from:
Martin Gürtler
Prof. Dr. Peter Hennicke
Sylvia Kruse

Prof. Dr. Jos Lelieveld

For more information see:
www.wupperinst.org

www.mpch-mainz.mpg.de

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1 Background to the Survey

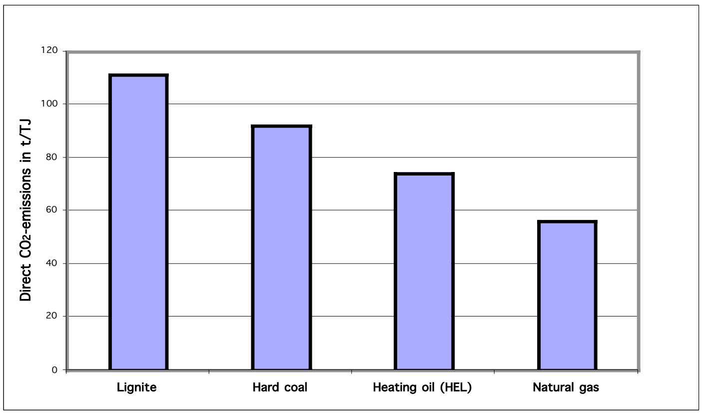
Fossil fuels supply over 90% of the energy used by the industrialised nations of Europe to generate electricity, power and heat. At the same time, the production and transmission of these fuels significantly contributes to the greenhouse gas emissions of the exporting and importing nations. It is the contribution made by natural gas to these emissions, in particular the climatic relevance of the natural gas exported by Russia to Germany as compared with other fossil fuels, which is the subject of the research project presented in this report.

E.ON Ruhrgas AG[1] asked the Wuppertal Institute for Climate, Environment and Energy and the Max Planck Institute for Chemistry to conduct a comprehensive measurement campaign aimed at closing existing gaps in available data and to complete the knowledge of the emissions from the natural gas process chain from Russia to Germany.

A detailed analysis of existing studies, data and process chain analyses (cf. Lechtenböhmer et al 2003, Wuppertal Institute 2003) was undertaken before the research project commenced.

1.1 The emission characteristics of different fossil fuels

If we compare the level of direct CO_2 emissions, i.e. emissions generated on site during combustion independently of the upstream process chains, we find that the ranking of fossil fuels is as shown in Figure 1. This shows natural gas as having the lowest direct emissions, with approximately 56 t CO_2 per TJ[2]. If in addition we consider the high efficiency of gas-fired power stations (as much as 58% in modern gas fired power plants), then natural gas presents a very positive picture compared with the other fossil fuels in terms of the greenhouse gas emissions caused by its use. That the level of direct carbon dioxide emissions can vary only slightly with fuel quality and combustion technique is not disputed by experts in the field, and so is not part of the current debate on climate policy Rather, this debate focuses primarily on quantifying the so-called indirect emissions from fossil fuels. Accordingly, significant differences can be found here in fuel production methods, fuel



Source: Wuppertal Institute 2004, based on data from German Ministry for Environment (2003)

Figure 1: Comparison of direct CO2 emissions of fossil fuels

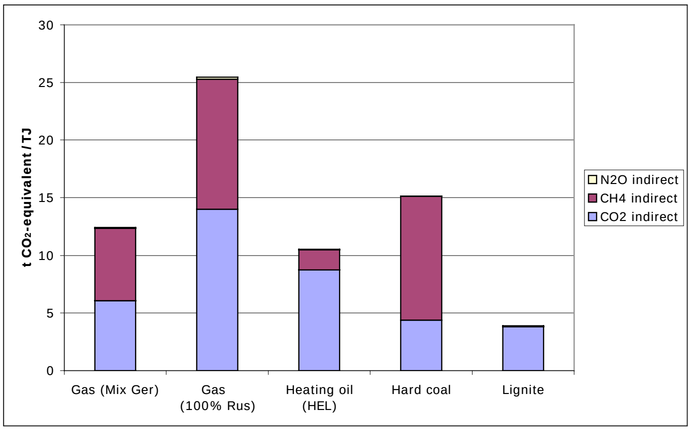
1 formerly Ruhrgas AG

2 Heating oil (HEL) 74 t/TJ; hard coal 92 t/TJ; lignite 111 t/TJ (source: Umweltbundesamt 2003); emissions of CH_4 and N_2O play virtually no part in modern combustion techniques. In stationary combustion systems in Germany they are usually less than 1 % of total CO_2 - equivalent emissions.

processing (benefication) and fuel transmission, and in the greenhouse gas emissions generated by these process steps. Besides CO_2, emissions of other greenhouse gases are also significant, above all CH_4. By contrast with direct emissions, it is the assumptions that are made about sources of supply and about the losses along the transmission route that are decisive here.

1.2 Importance of indirect emissions

A comparison of the indirect emissions from the production, processing and transmission of the various fossil fuels that play a role on the German market indicates that they are relevant with almost every fuel (cf. Figure 2). CH_4 and CO_2 emissions are of equally high significance, whereas the emissions of nitrous oxide (N_2O) are negligible. The emissions in the upstream process chain for natural gas (the current supply mix in Germany) are of a comparable order of magnitude as for example for hard coal and heating oil (HEL)[3]. Only the emissions of lignite are significantly lower than those of other fossil fuels, as here the CO_2 emissions associated with the energy consumed by mining are almost the only relevant factor. Whereas with hard coal it is the pit gas emissions that are of major significance besides the energy actually spent on mining the coal. With the current supply mix for oil the upstream emissions are generated by a large number of different processes (e.g. transportation by ship, the supply of heat for production and processing etc.). With natural gas, two factors of relevance are the energy spent on transportation and the release of gas from leaks.



Source: Gemis 4.13 (2002)

Figure 2: Indirect emissions from the upstream process chain of the fossil fuels used in Germany according to GEMIS

There is potential for natural gas to be released in the regions of production (e.g. during drilling, blowing out boreholes and processing), during transmission (chiefly from the combustion of drive gas in compressor stations, as well as maintenance and leaks) and during final distribution.

In this case it should be remembered that compared with the carbon dioxide emitted during combustion, uncombusted natural gas with methane as its main constituent has 21 times the greenhouse gas potential[4].

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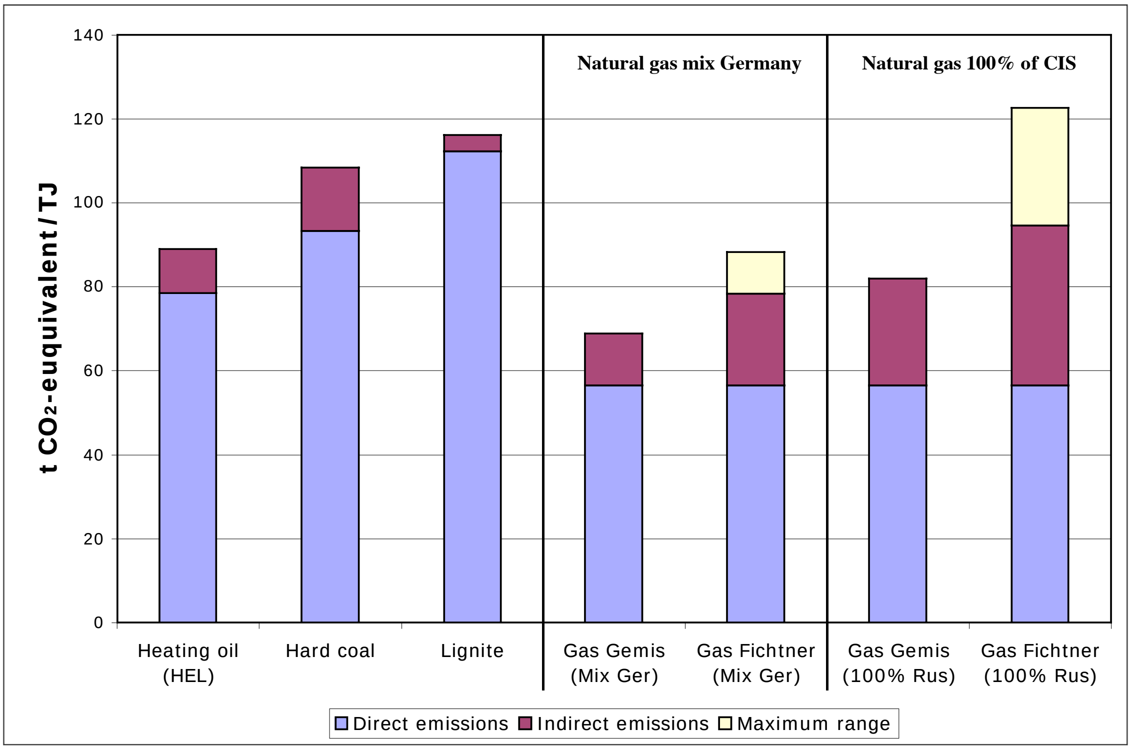
3 According to figures in Gemis (Öko-Institut [Institute for Applied Ecology] 2002)

4 The latest report by the IPCC (Third Assesment Report (IPCC 2001) puts the greenhouse gas effect for methane at 23 times that compared with CO_2 and over a period of 100 years. However it is the Second Assessment Report (IPCC 1995) which is legally binding for the issues associated with the Kyoto Protocol, and that puts the greenhouse gas potential at 21. It is this figure of 21 which is therefore used in the calculations presented.

Figure 2 makes clear however that – if we follow the data so far assumed in GEMIS[5] – the emissions of the upstream process chain of natural gas would roughly double if all of the natural gas sold in Germany were imported from Russia. If we were to use other information then the indirect emissions would be even far higher (cf. Figure 3).



Source: own calculation Wuppertal Institute, Gemis 4.2 (Öko-Institut 2002), Fichtner (2001)

Figure 3: Direct and indirect emissions of fossil fuels by selected reference parameters and data

It is the level of indirect emissions of natural gas production and transmission in Russia therefore which is the decisive factor in an assessment of the impact on climate of the fuels used in Germany. According to the requirements of the IPCC[6] and the Kyoto Protocol, greenhouse gas emissions are to be attributed to the country in which the emissions are released; in the case of natural gas imported from Russia, this is Russia and the transit states. In terms of a global consideration of the discharge of climate-relevant greenhouse gases however, the upstream emissions of the fuels used in Germany and Europe are also important to the climate debate in these regions.

In the past, assumptions about the level of indirect emissions of natural gas along the Russian supply chain were based on rough estimates only (e.g. Rabchuk et al, 1991). In some cases these emissions were estimated to be 5% of the produced gas, far higher than the emissions of other producing countries that ranged from 0.7 to 1.5%. It

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5 GEMIS 4.13 (Öko Institut [Institute for Applied Ecology] 2002) „Global Emission Model for Integrated Systems“ – a computer aided analysis model for mapping process chain systems and climate balances; together with Ecoinvent, it is currently the emission model most frequently used in the field of fuel process chains.

6 Intergovernmental Panel on Climate Change

was not until the mid nineties that two measurement campaigns undertaken by Ruhrgas AG together with Gazprom (Kaesler et al. 1997; Ramm 1997; Ruhrgas 1998) produced realistic reference figures for emissions from the production regions and along the transmission route; these figures were made available to the public in 1999 in an article by Dedikov and others. Measurements were taken at the production plants in Yamburg, at two compressor stations in Western Siberia and on export gas pipelines in the central corridor. The collected data was used to extrapolate the emissions for the entire Gazprom gas transmission network. The mid nineties also saw a further measurement campaign carried out by the US EPA[7] together with Gazprom; the results of this campaign have not been published. Both measurement campaigns arrive at comparable results, according to which emissions from the export network – not including the distribution networks inside Russia – can be assumed to be approx. 1% of the produced Russian gas.

1.3 Reasons for a new measurement campaign

A comparison of the various studies of the indirect emissions of natural gas supplied to Germany shows that the wide spread of results is due almost entirely to the disparate information about indirect emissions of the natural gas of Russian origin.

Most studies and analyses refer to similar primary sources. These primary sources are chiefly the theoretical estimations in Zittel (1997) and results from the Ruhrgas/Gazprom measurement programme referred to above and which are summarised in Dedikov (Dedikov et al. 1999). Some sources however have referred to earlier studies (e.g. DGMK 1992), while others have added their own rough estimates to existing investigations. Two cases in point are the study by Fichtner (2001), in which a detailed listing and explanation of the existing investigations and measurement campaigns is followed – with almost no comment or clear justification – by a significantly higher rough estimate by Greenpeace (2000) as the basis for calculations (cf. Fritsche, Matthes 2001), and the calculations by Rheinbraun AG (Ewers, Renzenbrink 2002) that are based on internal material of the ‘Forschungsstelle für Energiewirtschaft‘ (Research Institute for Energy Economy). Both of these studies assume very high fuel gas consumption (compressor drive) and, in particular, extreme leakages from transmission in Russia.

It would appear therefore that previous measurements are not accepted by all sides and/or are not always used to quantify the emissions, and the public has been left with a degree of uncertainty in evaluating the true climate relevance of Russian natural gas.

The main areas of criticism of the measurements made during the 1996/97 campaign are the small number of measurement sites and the lack of transparency and missing detail of documentation of the results and the activity data used. Another major point of criticism of the Ruhrgas and Gazprom results according to Popov (2001) is the extrapolation of the results to the entire system. Popov urges more accurate error analysis, disclosure of the activity data that were used and the creation of specific emission factors for individual items of plant (modelled on the US methodology).

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[7] Measurements at 4 stations in central and southern Russia. unpublished report, cited in Popov 2001

Besides this essentially justified criticism, studies by Fichtner (2001) and others contain relatively blanket qualifications of the existing surveys that refer in particular to the fact that only one production region, only two compressor stations and 630 km of relatively new pipelines were analysed. Even so, these doubts about the representative nature of previous studies usually lead to quoting significantly less accurate blanket statements that arrive at much higher emission estimates.

At the end of 2002 therefore, Ruhrgas AG and Gazprom decided to undertake a further survey that would address the criticisms levelled at the earlier measurements. Their aim was to obtain scientifically sound and transparently acquired knowledge about emissions from the Russian export gas network that could stand up to critical scrutiny. Therefore, the Wuppertal Institute for Climate, Environment and Energy and the Max Planck Institute for Chemistry, as independent scientific bodies, were asked to develop a valid measurement programme based on internationally accepted methods, to critically oversee its implementation and to use the measurement results and operational data to extrapolate the emissions of Gazprom's export mains to Europe.

The project received extensive technical and logistical support from Ruhrgas, Gazprom[8], the VNIIGaz Institute[9] and the three subsidiaries of Gazprom in whose network the measurements were carried out.

1.4 Limits of the study

This present study investigates all of the greenhouse gas emissions associated with the production, processing and transmission of natural gas exported from Russia to Western Europe, that is to say it considers not only the much debated methane emissions from leaks, maintenance work and breakdowns but also the emissions of carbon dioxide and nitrous oxide from the use of energy for gas transportation. Other emissions from the heating of buildings, motor vehicles and material consumption for infrastructure are negligible by comparison, and are not investigated in any more detail here (cf. Krylov 2001 and Gemis 2002).

The Russian gas exported to Germany and Europe comes from the production regions of Western Siberia and is transmitted to Europe over two long-distance gas corridors, the Central and the Northern Corridor. This study focuses on these Gazprom pipelines running to Germany and Western Europe, including their compressor stations and gate valves.

It does not provide any insights into the situation in those gas distribution networks used for Russian consumption.

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[8] The Gazprom public limited company of Moscow is the world's largest producer and transporter of natural gas. Nearly all of the gas that is exported from Russia to Western Europe is produced by Gazprom, which is also the sole operator of the natural gas long distance transmission networks in Russia.

[9] The VNIIGaz Institute in Moscow is a subsidiary of Gazprom. It is the leading institute that undertakes scientific and technical studies into all aspects of gas extraction, transmission, processing, distribution and use in Russia. The measurements in Russia were monitored by engineers from the VNIIGaz Institute. VNIIGaz also provided extensive data about Gazprom's export network.

The quantities of natural gas released in extraction and processing are included in the calculations. The data for this is based on the considerations of the pilot study for this research project (Wuppertal Institute 2003), including above all the study by Zittel (1997) and the results of the first measurement campaign by Ruhrgas/Gazprom (Dedikov 1999; Ruhrgas 1998; Ramm 1997). No new measurements of releases from extraction and processing were carried out.

In order to determine the emissions of natural gas supplied to the German market, the results obtained for Russia were extrapolated to the transit corridors in the Ukraine, Slovakia and the Czech Republic and in Belarus and Poland. These pipelines were assumed to have a similar technical configuration to those in Russia.

2 The natural gas long distance transmission network in Russia

A large part of the world's natural gas resources is to be found in the gas fields of Russia. Most of the gas exported to Western Europe in past and future decades comes from the Western Siberian gas fields around Yamburg and Urengoy. The gas produced here has high methane content of approx. 97%[10] and so requires only minimal pretreatment. Two main export corridors, the so-called Central Corridor (CC) and the Northern Corridor (NC) (see Fig. 4), are used to transport the gas to Western Russia and on into Central Europe

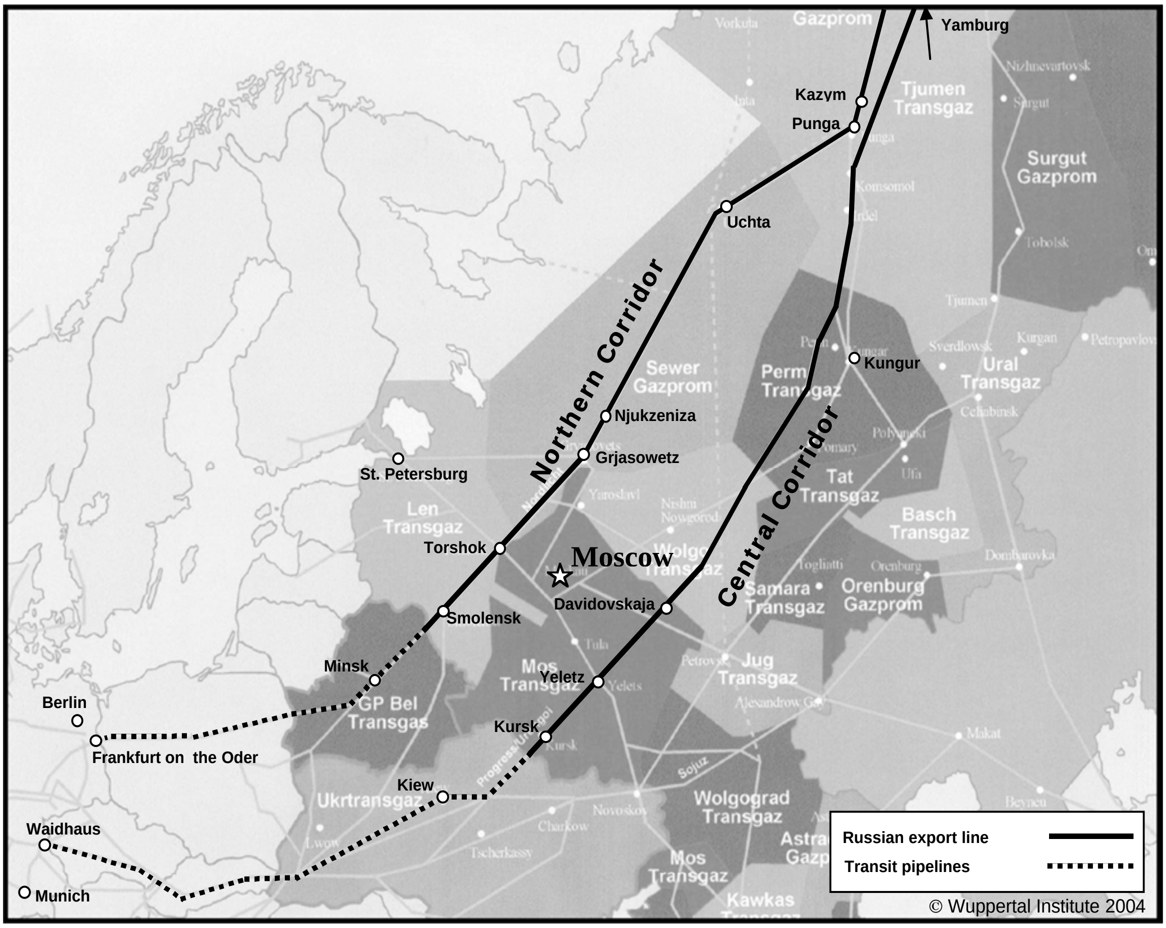

Figure 4: Overview map of export and transit corridors

The pipelines of the Central Corridor considered here were constructed in a number of different phases during the eighties and nineties, and in part follow pre-existing routes. The Central Corridor begins at Yamburg, turns south at the Urals and then runs south-west from Kungur south of Moscow, via Kursk to the Ukrainian border, where the pipeline continues on across Slovakia and the Czech Republic to the German border at Waidhaus (east of Nuremberg). The older Northern Corridor (commissioned from

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10 The mean of current extraction in Yamburg. The level of CH_4 in the gas entering the pipelines is over 98%.

around 1970 onwards) starts from Urengoy and initially runs parallel with the Central Corridor; after crossing the Urals it runs through northern Russia, passing to the north of Moscow before crossing the border with Belarus then, as the Yamal-Europe Pipeline, it crosses Poland to Frankfurt an der Oder on Germany's eastern frontier.

Table 1: Characteristics of the Gazprom gas network and the export corridors

Indicator	Unit	Gazprom* Long-distance transport system	Export corridors**		Corridors total in % of Gazprom
			Central	Northern	
Pipeline length	km	153.000	22.000	12.000	22%
Length of corridor	km		3.376	3.075	
Compressor stations	number	324	30	23	16%
Machines	number	4.047	930	634	39%
Installed power	MW	41.066	14.544	5.442	49%
Gas transportation capacity	thousand bn m3*km/a	1.574	541	347	56%
Gas production (Gazprom total)	bn m3/a	560			
Gas export volume (central europe)	bn m3/a	126	58	54	89%

*Source: V.N. Dedeschko (OAO Gazprom), 2001
**Source: calculation Wuppertal Institute according to internal data of Gazprom/VNIIGaz, 2004

The two corridors are operated by different regional gas companies[11] that all belong to the parent group, Gazprom. The corridors cover a distance of 3,075 km (Northern)[12] and 3,376 km (Central) [13] with a total pipeline length of over 34,000 km, accounting for 22% of Gazprom's total long distance gas pipelines. They export some 112 billion m^3 of natural gas to Europe each year. This is roughly 90 % of all exports by Gazprom to Europe, and some 20% of all of the gas produced annually in Russia (Gazprom/VNIIGaz 2004; Dedeschko 2001).

In the Central and Northern Corridors the pipelines consist for the most part of 4 – 6 parallel pipe runs with diameters of mainly 1420 mm and an operating pressure of 75 bar[14]. In order to maintain the pressure necessary for transmission, the gas is compressed and cooled at compressor stations (see Fig. 7) located at intervals of 100 to 150 km. The total rating of the compressors installed in the 30 compressor stations on the Central Corridor and the 23 stations on the Northern Corridor is almost 20,000 MW. The age of the compressors (their ratings range from 6 MW to 25 MW) in the Central Corridor is lower than that in the Northern Corridor (cf. Fig. 5), according to the date of commissioning. 10 MW compressors are used mainly in the Northern Corridor, while the Central Corridor has more powerful 16 MW machines for the most part.

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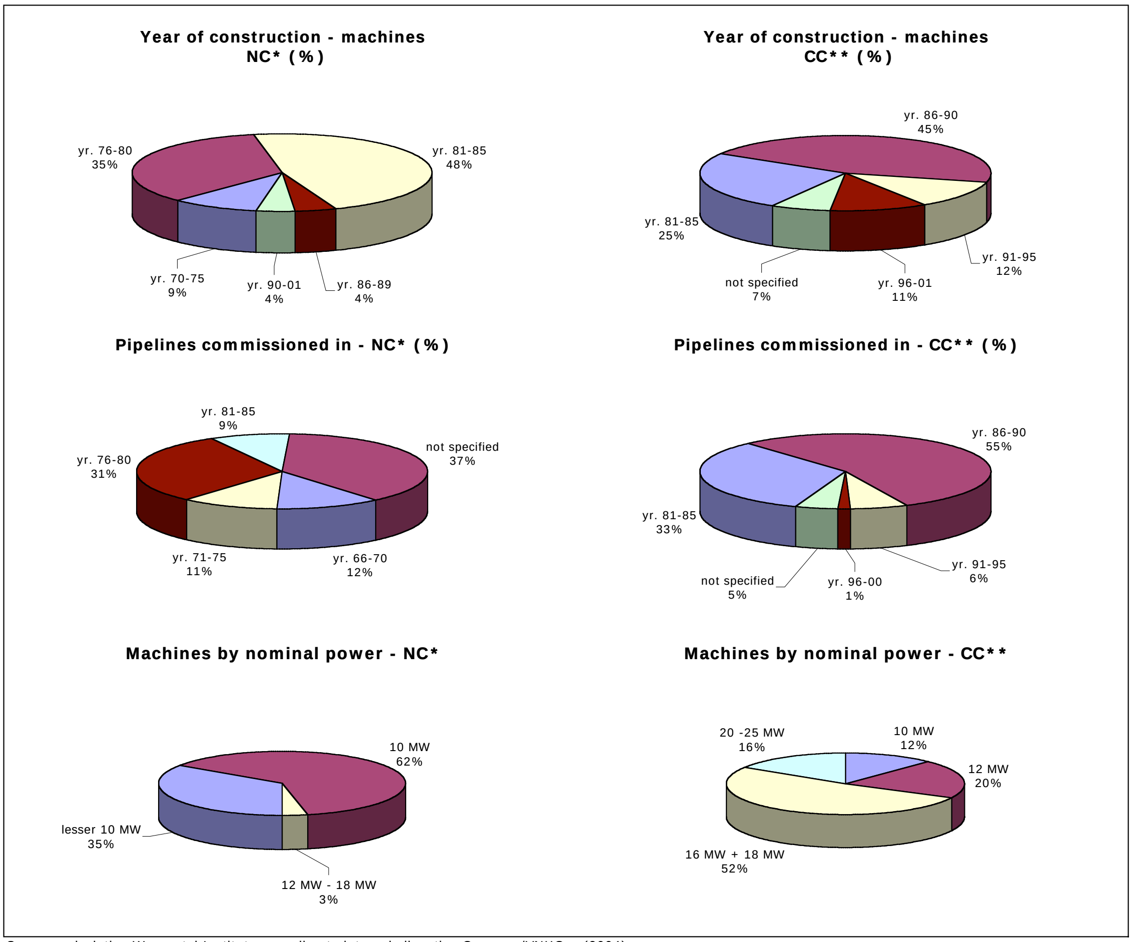
11 Tyumentransgas (Western Siberia, CC + NC), Severgazprom (NC), Permtransgas (CC), Volgotransgas (CC) and Mostransgas (CC)

12 only the export section in Russia; includes the pipeline section in the transit countries NC: approx. 4,300 km

13 only the export section in Russia; includes the pipeline section in the transit countries CC: approx. 5,500 km

14 On the Northern Corridor pipe diameters are 1020 mm in places and the pressure is 55 bar



Source: calculation Wuppertal Institute according to internal allegation Gazprom/VNIIGaz (2004)
* Northern Corridor
** Central Corridor

Figure 5: Age structure and rating of the compressors and pipelines in the export corridors

3 Measurements in the gas export network in Russia

Based on the findings from the previous data (see Section 1.3), the Wuppertal Institute designed a measurement programme for determining gas releases in the Russian gas export network. This measurement programme, the actual measurements and the extrapolation and error analysis were designed and implemented in accordance with the relevant requirements for greenhouse gas inventories (IPCC 1996, 2000; GRI/US EPA 1996; Gazprom/VNIIGaz 2000). A total of three measurement campaigns at 5 different compressor stations and their associated sections of pipeline operated by three subsidiaries of Gazprom were carried out in the spring and autumn of 2003 together with the Max Planck Institute for Chemistry[15]. The following sections give a brief account of how the sites were selected, how data was collected and how measurements were carried out and documented, and describe the subsequent calculations and the respective quality assurance measures that were taken.

3.1 The sites

The sheer size of the Gazprom export gas network makes it impossible to investigate all of the stations and sections of pipeline in detail in a measurement campaign of this type. We therefore made a representative selection of compressor stations and their associated pipelines in both export corridors, which we believed would reflect the circumstances of the whole export gas network as best as possible and necessary. It was a requirement, that the sites should be spread between both export corridors and operated by different gas companies, and should be exposed to different geographical and infrastructural factors. Further selection criteria were a representative cross-section of age and types of compressors and pipelines sections.

Table 2: Selected stations and surveyed compressor and pipeline sections of the 2003 measurement campaign, with the ages of the plant

Overview of the measurement campaign 2003							
Regional branch	Station	Shops measured	Machine / compressor		Pipeline - inspection / measurement		
			Power	Year of commissioning	Built in	Overflight	Intersection valves
Mostransgaz	Davidovskaja	1 (electr.)	7 x 12,5 MW	1985	1983-1988	300 km	1
	Kursk	1 (gas)	3 x 22,2 MW	1985	1983-1988	300 km	4
Severgazprom	Uchta	1 (gas)	6 x 10,0 MW 2 x 16,0 MW	1982 2001	1969-1977	1200 km	6
	Njukzeniza	3 (gas)	5 x 6,0 MW 13 x 10,0 MW 2 x 16,0 MW	1986 1977-1988 2001	1969-1981	580 km	8
Tjumentransgaz	Kazym	2 (gas)	6 x 6,0 MW 6 x 10,0 MW	1972 1977	1971 - 1977	-	6
Total	**5 Stations**	**8 Shops**	**50 Machines (534 MW)**			**2380 km**	**25**

Source: calculation Wuppertal Institute according to internal documents of Gazprom/VNIIGaz (2004)

Because of the necessary organisational preparation, the sites were selected jointly with Gazprom and the VNIIGaz Scientific Institute who were also involved in the measurements. Even though a purely random sample was not possible for practical and pragmatic reasons, we were nevertheless able to ensure that particularly the compressor types and dates of commissioning and pipelines of the selected stations were representative of the structure of the gas export network (see Table 2).

15 with the support of Gazprom, VNIIGaz and Ruhrgas AG, see 1.3

Figure 6: Measurement campaigns on the Russian natural gas export pipelines

The first phase of the measurement campaign was carried out in April 2003 on the Central Corridor with the gas transmission company Mostransgas at the compressor stations and pipelines in Davidovskaya and Kursk, south of Moscow. The second phase of the campaign took place in Northern Russia at the two stations of Uchta and Nyukzeniza operated by Severgazprom. Finally, the third phase of the campaign was conducted at the Kazym station (Tyumentransgaz) in Western Siberia in October 2003 (cf. Fig. 6).

The scope of the 2003 measurement campaign is shown in Table 2. It shows that extensive measurements were undertaken at 5 compressor stations belonging to three different gas companies on the Central and Northern Corridors. In all, 50 compressors of different types and ages as well as 25 pipeline intersections were investigated. Approx. 2380 km of pipeline were also surveyed from the air by helicopter overflight. At this point it is worth remembering that the 1996/97 measurement campaign took measurements at just two compressor stations belonging to a single gas company with associated pipelines, and over 600 km of pipeline in a different region. The sites of the 1996/97 and 2003 campaigns are shown in Figure 6.

The measurements described in Section 3.3 were carried out and extensive data was collected at all the stations and associated transmission lines (cf. 3.5), in strict compliance with quality assurance criteria (see 3.4).

3.2 Emission sources in compressor stations and pipelines

Essentially the emissions from the compressor stations and pipelines can be divided into technologically related discharges and unplanned emissions due to leaks and possible technical problems.

Leaks can occur at fittings and vents. The term ‘fittings‘ in this context is used to mean all valves, bolted assemblies, flanges etc., which may leak because of their design and direct association with the gas-bearing system of the compressor station and transmission line. Vents are devices which are usually installed for safety reasons and can discharge gas to atmosphere under controlled conditions, e.g. for venting purposes. The seal valves upstream of the vents may also leak, so quantities of gas may also escape from the vents. Gas leaks are also possible as a result of breakdowns, i.e. pipe fractures or accidents; the gas companies record their occurrence and the quantities of gas that escape and report to government authorities accordingly.

Natural gas is also unavoidably and/or deliberately released in a number of processes that take place in a compressor station. These processes include the seal oil systems at the shaft seals of compressors, the gas-controlled regulators of the fuel gas supplies, maintenance and repair work in which gas still in the compressor or transmission line is discharged to atmosphere, gas turbine start-up and shutdown sequences and filter cleaning operations (see 3.5). At the same time, natural gas is used as fuel gas to drive the turbines, leading to CO_2 emissions, which constitute the biggest proportion of total emissions from compressor stations.

The measurement programme described here was used to determine the unplanned amounts of gas leaking from pipelines and compressor stations as well as the planned releases from the fuel gas plants and the compressor seal oil systems. A systematic inspection and survey of individual plant sections was carried out in order to identify as many leaks as possible in these complex industrial plants.

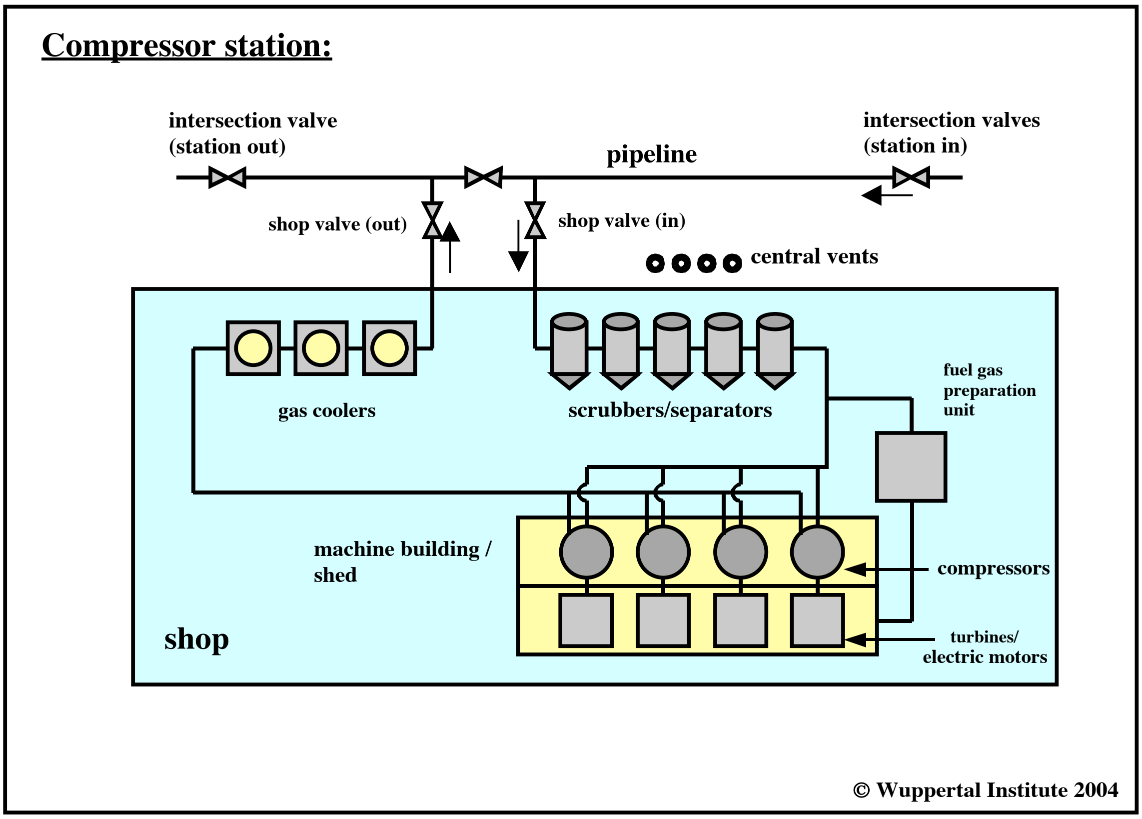


Figure 7: Typical schematic of a plant complex ('Shop') at a compressor station

Most Russian compressor stations in the export corridors consist of a number of plant complexes arranged in parallel, known as a 'shop', although this should not be taken to mean an actual shop building. Each 'shop' is allocated to a pipeline. A typical schematic of a plant area of this type is shown in Figure 7.

The gas passes from the pipeline into the compressor station through the 'inlet valves'[16]. It is cleaned before being passed to the compressor buildings. The compressor sets installed in these buildings are the main components of the plant area, each set comprising of a drive unit (gas turbine or electric motor) and the actual compressor. The compressor boosts the gas pressure to the level needed for onward transmission. The planned and unplanned emissions released by the machinery enter the atmosphere via vents on the roof of the building and other machine vents outside the building. The gas turbines that are mainly used to drive the compressors are fed with gas tapped from the line. The necessary gas supply to the machinery is regulated by the fuel gas supply, which is annexed to the machine shop in most cases. As the temperature increases as a result of the compression process, the compressed gas is cooled to the optimal transmission temperature where necessary before being returned to the pipeline.

16 The word 'valve' is used here as a collective term for different types of fitting. The most common types are ball valves, needle valves and gate valves.

3.3 The measurements

One working week was available for the measurements at each of the five sites surveyed. We worked with a number of survey teams (usually 4 – 5 persons) to make sure that as many of the selected machine shops as possible could be inspected and measured. Care was taken to ensure that each team had sufficient technical know-how, both in regard to the plant installations and the measuring equipment, to perform thorough measurements and ensure the quality of the results obtained. All measurements were closely monitored by the Max-Planck-Institute and Wuppertal Institute who checked that the measurement procedures were correct and ensured that all aspects of the plant were fully covered.

Leaks from fittings were measured in two stages. The first stage involved screening in which as many plant items as possible were checked with sensitive CH_4 detectors. Where a high methane concentration[17] was detected, the gas escape point was recorded as a potential leak in the screening log, assigned a leak number and marked. It was possible to record the total number of leaks for the screened items of equipment on the site. The second stage involved volume measurements at a large number of the detected leaks[18]. To measure the volume, the fitting was first enclosed in foil, i.e. protected from outside influences, so that the volume of escaping gas could be accurately measured by extraction. The leakage rate in m^3 CH_4 per hour was then calculated from the volume of extracted air and its methane concentration. The volume flow was converted to standard temperature and air pressure conditions, and the measured methane concentration was corrected as necessary. These figures formed the basis for further statistical calculations (cf. Chapter 4).

The vents that are installed on machines, fittings and fuel gas supplies for the controlled discharge of gas underwent direct volume measurements. The sections of gas pipeline that belong to the stations have intersections at intervals of approximately 15 – 30 km (see Fig. 8). These intersections can be used to isolate the leg for maintenance or repair purposes or to discharge the gas or divert it into other lines. The pipeline intersections are equipped with fittings and vents from which gas can escape if there are leaks in the upstream isolation valves. The measurements were made applying the same two-stage principle as was used for the compressor stations.

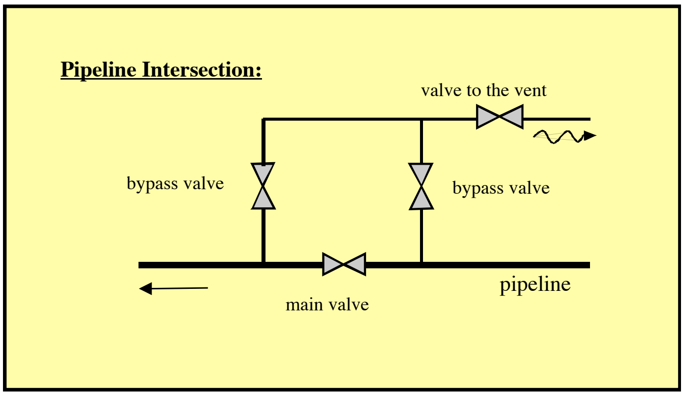


Figure 8: Typical schematic of a gate valve node in a pipeline

[17] Leaks were marked from a measured methane concentration of approx. 0.3 volume per cent and over at the leak site. Significant emissions only occur at methane concentrations over 1 - 2 % however.

[18] At the vents the volume measurement was always carried out in direct conjunction with the screening process.

We also flew over the pipeline sections belonging to the compressor stations (a total pipeline length of 2380 km) at a height of approx. 50 m, checking them for high methane concentrations with the ‘Aeropoisk III‘ laser leak detector. It was possible to reliably detect leaks of the order of approx. 200 – 500 m^3/d and more using this method.

3.4 Documentation and quality assurance

Before the measurement campaigns commenced, the various steps and procedures were agreed in detail and the personnel involved made aware of their respective tasks. The documentation consisted of standard measurement and day logs (identical in both German and Russian), in which each measurement had to be recorded together with particulars of the survey team, the site / plant section where the measurements were taken and the number of screenings, detected leaks with their leak numbers and the volume measurements that were carried out. These measurement logs were checked daily and signed off by the German and Russian leaders of the survey teams.

The measurements were monitored closely and continually by personnel from the Wuppertal Institute (WI) and the Max-Planck-Institute (MPI), to confirm that the correct technical procedures were being applied and to ensure that all aspects of the plants were being covered. The MPI checked each step of the measurements and above all ensured the appropriate and correct use of the instruments. All potential influencing factors and errors were considered and eliminated. Numerous tests, cross-checks and inspections attested to the reliability and quality of the screenings and emission measurements that were carried out.

The instruments used were new and were calibrated by their manufacturers. The CH_4 instruments were checked in the Ruhrgas laboratory in Dorsten before the campaign started. After the campaign the instruments were examined by Ruhrgas personnel in Moscow[19]. The corresponding measurement curves were used to correct the data and calculate errors.

An access database was used to evaluate the measurement logs. Each detected leak and each measurement was transferred – in most cases on site – from the log to the database by WI personnel so that a direct plausibility check was possible.

This ensured the ongoing monitoring and verification of the measurement programme by the two institutes. Using the leak numbers, each individual identified leak can be traced from its entry on the original logs through all data processing operations right down to the final result extrapolation. This also allowed a continuous check of the subsequent statistical analyses for completeness and possible transfer errors. Appropriate check routines were carried out in all data processing operations.

For the aerial surveys of the pipelines at four compressor stations using helicopters and a laser leak detector (Aeropoisk III), we created separate logs in which the results and the Aeropoisk strip charts were recorded and confirmed by the personnel involved in the aerial survey.

[19] All measurements were also checked with Russian instruments by the VNIIgaz Institute.

A technical report was prepared by experts from the institutes on completion of the measurements at four stations. This report includes a list of the measurements taken, the surveyed equipment as well as foreseeable and/or calculated results. It also indicates the maximum measured leak rates in m^3 CH_4 per hour for most stations. The technical reports were checked and signed off by all the parties involved (Wuppertal Institute, Max Planck Institute, VNIIGaz Institute, Ruhrgas, Gazprom, transmission company and station manager) (Gazprom et al 2003a-d).

All the agreed standards and quality assurance measures were also documented in a project manual specially created for the measurement campaign. This manual serves as a compilation of documents, regulations and procedures that were established to steer the survey activities and provide evidence of their implementation.

The measurement logs and technical reports, completed survey sheets with operational data and numerous other documents, site plans and detail drawings, valve schedules etc. were all archived by the Wuppertal Institute.

3.5 Determining other operations-related emissions

As well as the unplanned gas losses due to leaks, there are also so-called operations-related discharges through the operation of the gas transmission system[20]. These discharges are a function of the mode, operating characteristics and parameters of the machinery and plant.

They include CO_2 emissions from the fuel gas needed to drive the gas turbines as well as releases of gas on machine startup and shutdown and when machines and pipelines are vented for maintenance and repair purposes. Small amounts of natural gas are also released in the cleaning of dust filters and traps.

These emissions can be determined from operating data about fuel gas usage, service schedules, machine starts and running times etc. and from typical design parameters for the Russian machinery and pipelines.

A prepared questionnaire was used to gather a large amount of operational data (fuel gas usage, transmission volumes, maintenance and repairs, regular aerial pipeline surveys etc.) at the sites during each measurement campaign in liaison with the station managers and the engineers responsible.

At the request of WI, Gazprom provided a large amount of internal operational data for both export corridors with which to calculate the quantities of emitted gas over the entire export route (Gazprom/VNIIGaz 2004).

By comparing the operational data collected in situ and data from literature, other surveys and plausibility checks, it was possible to arrive at typical emission parameters for all operations-related emissions from the Russian export network. The operational data provided by Gazprom allowed us to extrapolate the emissions on both export corridors (cf. Chapter 4).

[20] Gazprom also refers to the consumption of gas for its main and secondary technological processes as ‘technological own requirements for gas transmissions‘.

Table 3: Typical emission factors for operations-related discharges from compressor stations and long distance pipelines and for breakdown-related gas losses

	Unit	Mean value[1)]
Long distance pipelines		
Maintenance and repairs	m^3 CH_4/km *a	3.750
Breakdowns	m^3 CH_4/km * a kg CO_2/km *a	284 782
Compressor stations		
Startup/shutdown emissions	m^3 CH_4 per compressor * a	15,400[2)]
Shop venting	m^3 CH_4/shop * a	105,000
Filter cleaning	m^3 CH_4/shop * a	44,359

1) Specific emission factors based on this with ranges were used for the calculation (see Chapter 4)

2) Detailed data was used for each machine type for all shops in the northern and central corridors; the emissions range from approx. 200 to 3,900 m^3 per startup/shutdown cycle depending on type.

Source: Own calculations based on VNIIGaz/Gazprom 2004; Zittel 1997; Kaesler/Ramm/Jansen 1997; Ramm 1997; Ruhrgas 1998; surveys by WI in 2003 at 5 compressor stations operated by Gazprom

Gazprom also provided detailed information about unplanned gas leaks from pipelines and compressor stations (gas losses due to breakdowns) (Gazprom/VNIIGaz 2004). Whenever such an incident occurs, the gas loss is so substantial that it is readily detectable from the direct drop in pressure at the nearest measuring station or nearest compressor station. In most cases (approx. 60 %) the escaping gas ignites as a result of the friction caused by the enormous pressure. Both CO_2 and CH_4 are emitted to atmosphere as a result.

The gas companies report the breakdowns to Gazprom and the authorities (Environment Ministry). All breakdowns, including details of the cause of the incident, the amount of greenhouse gases emitted and whether the gas ignited, are known from these reports.

It is also worth mentioning in this context that the pipelines are routinely checked and maintained with a view to the early detection and remediation of any disruptions and leaks that could affect the transmission of gas. Regarding pipelines under high pressure, leaks attract attention through loud whistling or freezing or because the sand cover is blown away, so the likelihood of leaks going undetected is minimal or nil. Each pipeline section also has a section supervisor who conducts daily checks on individual sections of the route, recording any damage and reporting it to the station managers responsible. In addition, the pipelines are regularly overflown with a detector (Aeropoisk) which can record major methane losses from the pipeline from the air. The use of pigs to assess the condition of the pipelines and assist in identifying and dealing with potential problems before a leak can occur has been greatly intensified in the past 10 years, and many potential pipeline incidents have been prevented in this way (Ivanzov 2000)[21].

The frequency of maintenance work at compressor stations varies according to the number of hours which the machines run. Service intervals are laid down individually

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21 “Recent years have seen an increase in the use of pigs based on magnetic and ultrasonic technologies, thereby facilitating an assessment of the condition of the pipelines with high resolution power.“ (Ivanzov 2000 translated)

for each compressor type. Routine services of varying intensity are carried out approx. every 1,500 to 2,000 operating hours. Next come so-called medium-sized repairs after about 8,000 – 16,000 hours and finally general overhauls after some 16,000 – 25,000 hours.

When maintenance work is carried out, the particular machine or all the machines in a compressor shop are shut down and vented depending on the extent of the maintenance work. Gas remaining in the compressor is released to atmosphere. These gas emissions are already included in the operational data for compressor starts and stops. For major overhauls the connecting pipework in the compressor shop complex is also emptied, i.e. the entire shop is vented.

4 Calculating the emissions

The emissions of greenhouse gases for the export system of Gazprom are calculated in a number of steps. A distinction is made between extrapolating the measured CH_4 emissions (mainly from leaks) on the one hand and calculating other operations-related CH_4 emissions (see Section 3.5) as well the emissions of CO_2 and N_2O on the other. The first step was to calculate the emissions in the export network and in production and processing. Step two involved carrying out a Monte-Carlo analysis to ascertain the uncertainty of the result.

The emissions were calculated in a number of steps:

- Definition of the emission model, i.e. defining the emission equations for all emissions-relevant parts of the system and activities. These emission equations normally consist of an activity indicator (e.g. number of emitting fittings of one type) and an emission factor (determined from the measurements).
- Determining the emission factors:
  For the measured emissions, the average number of leaks identified during the surveys was determined for every individual component on the export corridors, and similarly the emission level of each leak was determined from the representative measurement results of leaks for the particular component type. The emissions from these components to be expected for the export corridors were then simulated in a separate Monte-Carlo calculation. As well as the anticipated mean emission value, the Monte-Carlo calculation also determined the corresponding probability density function (PDF).
  For the other emissions, the emission factors were calculated on the basis of data gathered on site and detailed statistics supplied by Gazprom. Information was also taken from literature references for comparison purposes (see Section 3.5). The uncertainty margins of these emission factors were created as an expert estimate on this basis. This was based on a conservative – i.e. in case of doubt high – emission estimate.
- The activity indicators consisted in turn of plant survey data, machine run-times and servicing, repair and breakdown statistics. Here again, margins were assumed where necessary.
- In the fourth step, the emissions were calculated and uncertainties in the emission model were determined. The maximum range (confidence interval) of the result was determined by carrying out over 10,000 separate calculations of the emissions of the export corridors (Monte-Carlo method[22]). In each of these calculations, the

[22] The Monte-Carlo method is internationally regarded as the most appropriate method for determining the uncertainties of greenhouse gas inventories (IPCC 2000 and GRI/US EPA 1996). In a Monte-Carlo analysis, an emission model is first developed and implemented in a Monte-Carlo programme. So-called 'probability density functions' must also be developed for all variables (mainly activity indicators and emission factors) . These functions reflect the uncertainty associated with determining and extrapolating the particular value. In the actual Monte-Carlo simulation, random values are taken for each variable from the spectrum of their probability density function and the emissions of the complete system are calculated by reference to these randomly selected parameters. This operation is then repeated n times so as to cover all possible combinations of value instances. The result is n values each with the probability of 1/n. From this range of values it is then possible to read off the

respective activity indicators and emission factors were randomly selected from the calculated / estimated probability distributions. For the overall result and for partial results also, this in turn produces a probability distribution of results which, as well as the mean value, i.e. the emission level, also tells us which spread of results we can expect and with which probability.

Table 4: Result of the Monte-Carlo analyses of CH_4 emission factors of the measured plant sections and plant items at compressor stations and pipelines

System section	Reference unit	Mean value *)	95% Confidence interval from	to
Plant item		----------	m³ per year	---------
Compressor stations				
Gas cooling and filters				
Vents	Shop	7.468	5.894	9.820
Fittings	Shop	860	633	1.146
Combustion, startup and pulse gas treatment	Gas-operated shop	145.270	51.324	420.413
Compressors				
Vents (excl. central vent)	Compressor	437.150	142.963	1.499.602
Fittings	Compressor	2.434	2.059	2.952
Central vent (compressor running)	Compressor	6.302	2.552	16.134
Central vent (compressor off)	Compressor	9.396	8.323	10.491
Seal oil system	Compressor	27.693	13.101	68.885
Pipelines (valve nodes)				
Vents	Pipeline intersection	43.310	27.074	77.829
Fittings	Pipeline intersection	3.535	2.455	5.711
*) Arithmetic mean of 10,000 Monte-Carlo simulations; because the probability distributions are not symmetrical, the arithmetic mean is not the mean value of the lower and upper limits of the confidence intervals.				

Source: Measurement campaign 2003, own calculations, Wuppertal Institute 2004

Two fundamental assumptions had to be made for the random-based model used here to extrapolate the emissions and their probability distribution. These were first, the assumption of identical distributions of leak incidence and emission levels of all the leaks from a component type, and second, the assumption of a virtually constant emission situation over the course of the year.

These assumptions are justified among other reasons because the state of repair of the plants is standardised by technical standards, service schedules etc. throughout Russia. This picture was confirmed by the situation on site at the five compressor stations we visited and by reports on other stations by other international experts (e.g. Venugopal 2003). Moreover the measurement campaigns were designed to have as wide a geographical distribution as possible and reflected both the spread of age

limits between which the result of the emission calculation – allowing for all uncertainties – will fall and with which probability. Combinations of characteristics that lie outside these limits can be discounted as improbable. (cf. IPCC, 2000) groups and of the different types of plant as well as climatic variations (see Section 3.2).

5 Result: Greenhouse gas emissions of Russian gas exports

5.1 Greenhouse gas emissions along the export corridors

The extrapolation, as described in the preceding section, of the greenhouse gas emissions from gas transmission pipelines in the export corridors, including production and processing in Russia, provides a detailed overview of the current emissions situation in the export network in Russia[23].

Table 5: Greenhouse gas emissions from the export corridors (2003)

GHG Emissions by plant section/mode	Million t CO_2 equivalent	Share
CO_2		
Turbine exhaust	37.27	63.0%
Power supply (for electric drives)	3.03	5.1%
Breakdowns (ignited)	0.03	0.1%
Total CO_2	**40.33**	**68.2%**
N_2O (turbines and power generation)	**0.58**	**1.0%**
CH_4		
Leaks from fittings and vents	**12.42**	**21.0%**
Leaks from compressors	11.07	18.7%
Other leaks from compressor stations	0.04	0.1%
Leaks from pipelines	1.31	2.2%
operational (measured)	**1.32**	**2.2%**
Fuel gas, startup gas and pulse gas supply	0.57	0.9%
Seal oil systems (shaft seals)	0.75	1.3%
operational (calculated)	**3.48**	**5.9%**
Compressor startup/shutdown	0.37	0.6%
Methane in turbine waste gas	0.09	0.2%
Maintenance/repairs to stations (incl. the venting of fittings and pipeline pigging)	1.05	1.8%
Maintenance/repairs to pipelines	1.97	3.3%
CH_4 from breakdowns	0.15	0.3%
CH_4 from underground storage (pro rata)	0.36	0.6%
CH_4 from power supply	0.48	0.8%
Total CH_4	**18.21**	**30.8%**
Total of greenhouse gas emissions overall	**59.12**	**100.0%**

Source: Own calculations, Wuppertal Institute 2004

Table 5 shows greenhouse gas emissions along the export corridors in 2003 by gas and source. It shows that almost 70 % of greenhouse gas emissions from gas transportation are CO_2, primarily the exhaust from the gas turbines used to drive the compressors, and the CO_2 from Russian power generation attributable to the electric

23 The emissions ascribed to the transit of gas through the Ukraine, Slovakia and the Czech Republic and through Belarus and Poland respectively are not presented in detail here. They are included in the next chapter in the calculation of indirect emissions of gas supplied to the German market however.

motors used for the same purpose[24]. CO_2 emissions from ignited gas from breakdowns by contrast are of almost no relevance. The same is true of N_2O which comes from the turbine exhausts or the power supply, and accounts for some 1 % of greenhouse gas emissions along the export corridors.

Just under 31 % of greenhouse gas emissions are due to the release of CH_4. Of this, a good two-thirds were emitted from leaks on fittings of the machines, compressor stations and valve nodes on the pipelines. Another significant proportion is due to the venting (i.e. the discharging of gas to atmosphere) of shop and pipelines for maintenance and repair purposes; taking the worst-case assumptions that were made, venting accounts for a good 5 % of greenhouse gas emissions along the export corridors. Other operations-related emissions are due chiefly to gas-regulated fittings and compressor seal oil systems (shaft seals). CH_4 losses can also be due to breakdowns, and here again a worst-case estimate was used which – for reasons of safety – is well above the detailed data we have about the actual breakdown related emissions in 2002 and 2003[25], to emissions from the storage facilities allocated pro rata to the central export corridor[26] and to the use of power.

In the final step, the emissions attributable to gas exports to Germany were determined from the total emissions on the export corridors. To do this, we determined the percentage of transmission power required to export the 31 billion m^3 of natural gas imported into Germany each year (plus respective# needed as drive gas and the emissions) out of the total transmission power of both export corridors. This is approx. 13 % of the total transmission power of both export corridors, or some 7 % of the total transmission power of Gazprom. The percentage emissions from production and processing were determined similarly. It was assumed that all of the amounts required for export including the drive gas were produced in Yamburg.

5.2 CH_4 emission characteristics

The emissions measured by the Wuppertal Institute and the Max Planck Institute during the 2003 measurement campaign can also be expressed as specific characteristic values. These values are often used in international literature to characterise the emission situation of natural gas systems (cf. Altfeld 2000, IPCC 2000). Table 6 gives an overview of the determined specific characteristic values compared with the results of the measurement campaign conducted by Ruhrgas and Gazprom in 1996/97, and shows that along the pipelines the emissions per kilometre of pipeline length were approximately one fifth lower than in the latter campaign. The characteristic value for leaks was somewhat lower than recorded in 1996. A significantly reduced number of leaks was found at the individual valve nodes compared with the 1996/97 campaign. The measures introduced since that time, such

[24] The emission characteristics for the power used for electrical traction were taken from Gemis 4.12.

[25] A number of current Gazprom publications show that in recent years activities designed to detect corrosion damage early and so prevent the main cause of breakdowns have expanded significantly (Dedeshko 2001, Ivanzov 2000, Inanzon, Miroshnitshenko o.J.).

[26] The upper bandwidth of the emission factors used by the International Gas Union (IGU) and IPCC (2000) for underground stores was applied here as the worst-case estimate for emissions (cf. Altfeld 2000).

as improved checks and inspections, improved sealing of fittings etc. have obviously had the effect of reducing emissions. The greater density of valve nodes along the Central Corridor has had the effect of increasing emissions in the extrapolation however, this density being about twice as high here as on the Northern Corridor and as was assumed in the calculations by Dedikov et al. (1999).

Table 6: CH_4 emissions for pipelines, compressor stations and production and processing – Comparison of the results of the 1996/97 and 2003 measurement campaigns

	Wuppertal Institute 2004	**Dedikov et al. 1999**
Pipelines		
Leaks	2,425 m^3/km*a	2,700 m^3/km a
Breakdowns	284 m^3/km*a	700 m^3/km a
Maintenance & Repairs	3,749 m^3/km*a	4,800 m^3/km a
Total	6,458 m^3/km*a	8,200 m^3/km a
Production and processing, Yamburg		
Operations-related emissions *)	0.09 % of production *)	0.04 % of production *)
Leaks	0.03 % of production	0.02 % of production
Total	0.11 % of production	0.06 % of production
Compressor stations		
Leaks	44,191 m^3/MW a	
Operations-related emissions	5,227 m^3/MW a	
Total	49,418 m^3/MW a	75,000 m^3/MW a
*) The difference in figures between Dedikov and WI is due mainly to a conservative estimate of the operating hours of the central flare. A large proportion of the emissions are passed through the flare so they are completely combusted as planned. However year-round combustion is not guaranteed owing to occasionally adverse weather conditions, which is why the figure of Dedikov et al. (1999) was based on a combustion rate of 70 % of the gas at the flare. WI 2003 on the other hand took a combustion rate of just 33 % of the gas as a conservative assumption based on Zittel (1997) .		

Source: 1996/97 measurements: Dedikov et al. 1999, 2003 measurements, own calculations, Wuppertal Institute 2003, 2004 (no measurements in Yamburg)

No new measurements were carried out in the areas of production and processing. Here we fell back on the results obtained by Ruhrgas and LBST in 1997 in Yamburg, with a more cautious assessment of the rate of combustion of the central flare producing a generally higher emission characteristic, at 0.11 % of the production volume (cf. Ramm 1997, Wuppertal Institute 2003).

Significantly lower emissions were found at the compressor stations than in 1996, with 49,400 m^3 per MW per year. Here, the bulk of the emissions were due to leaks which account for almost 90 % of the total emissions of compressor stations, clearly outweighing the operations-related emissions of the stations. The compressors in one shop in particular[27] were found to have high emissions. The older 6 MW compressors that are installed here show a significantly higher emission factor than all other compressor types. This is one reason why these machines are currently being replaced as a matter of priority. Without this compressor type, a characteristic value of approx. 12,000 m^3 per MW/a for the Central Corridor would be determined for the leaks from the other machines, a figure that accords well with Canadian results on the Central

[27] Shop 1 of the Kazym station in Western Siberia.

Corridor[28]. Even though there are no high emission 6 MW compressors on the Central Corridor and they only account for just under 20 % of the installed machines on the Northern Corridor, for the sake of prudence our calculations were carried out using the high emission characteristic including the 6 MW machines.

5.3 Specific emissions and uncertainty analysis

Because measurement campaigns as a rule can never cover all potential sources of emission at all sites, statistical uncertainties always remain. The chart in Figure 9 shows the main results of the uncertainty analyses performed on the emission calculations as bandwidths within which 66 % and 95 % of the anticipated results lie, i.e. there is a high (66 %) probability that the actual results lie within the bordered areas. That they lie outside the orange and grey highlighted areas (95 % confidence interval) can be ruled out with 95 % certainty on the other hand. The chart shows the uncertainties of the CO_2 emissions, the CH_4 emissions and of total greenhouse gas emissions separately.

CO_2 emissions account for almost two-thirds or approx. 5.6 t CO_2 equivalent/TJ of the total greenhouse gas emissions associated with Russian gas exports – from Yamburg to Russia's western border – from production, processing, transmission and underground storage[29]. Here the uncertainties are confined within narrow limits, i.e. the CO_2 emissions are between 5.0 and 5.9 t/TJ with 95 % certainty.

At 0.7 % of the gas supplied to Russia's western border or 3 t CO_2 equivalent/TJ, CH_4 emissions account for just one third of total emissions, although the uncertainties in emission determination and extrapolation are significantly higher here. For CH_4 this produces a typical 'right-skewed' distribution, i.e. the large majority of values are below the average as the latter is displaced by the smaller number of values that deviate upwards. As the upper limit of the probable value spectrum – allowing for all uncertainties – this results in an emission factor of 6.6 t CO_2 equivalent/TJ maximum, or just under 1.6 % of the gas for the CH_4 emissions from gas export (to Russia's western border). On the strength of the extensive statistical error analyses carried out here therefore, it can be taken as a certainty that the CH_4 emissions are below the value of 1.6 % of the natural gas transmitted to the western border[30].

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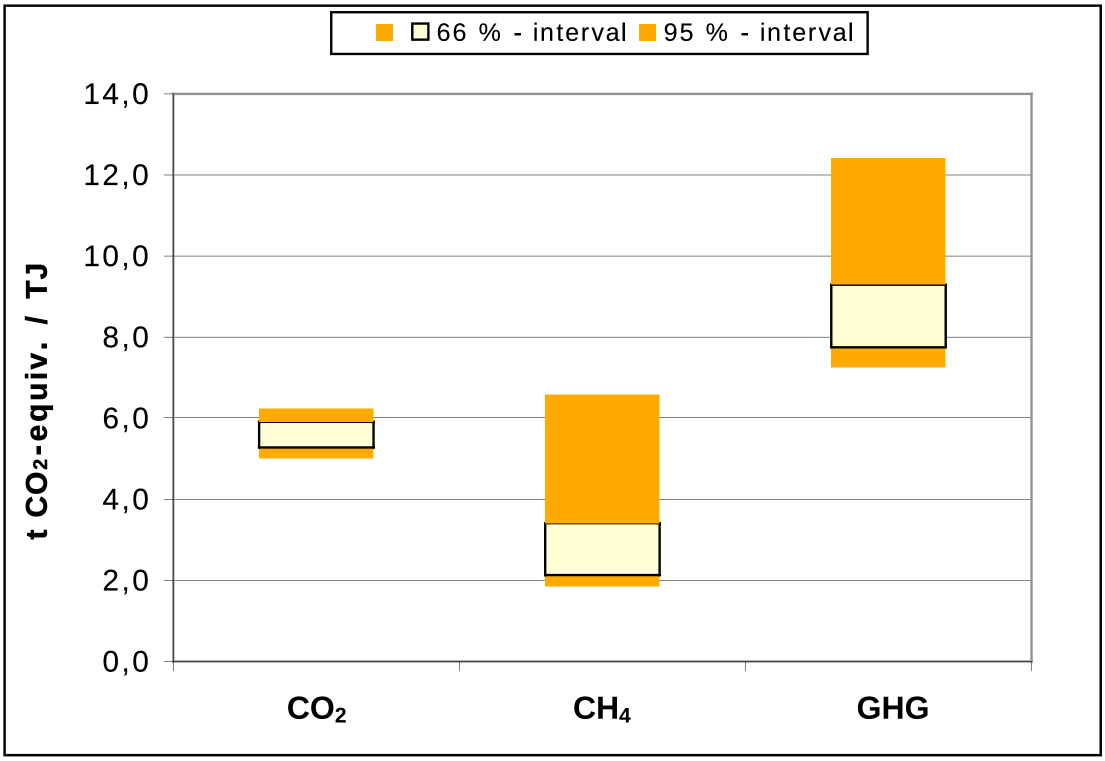
28 This figure also agrees with results obtained in 2001 by the Canadian gas company TransCanada in a Joint Implementation Project for methane emission reduction on more than 40 compressors at 2 compressor stations along the Central Corridor (cf. Venugopal 2003).

29 This also includes the pro rata emissions from production and processing. The weighting of the emissions in the overall results is therefore slightly different from the detailed results on the export corridors as given in Section 5.1.

30 The true value can be expected to be significantly lower than this given that the emission calculation is additionally based on 'worst-case assumptions' in many areas.



Source: own calculations, Wuppertal Institute 2004 (pro rata: production and processing, export corridors and underground storages, based on gas delivery to the western border of Russia

Figure 9: Confidence intervals of greenhouse gas emissions from Russian gas exports to Russia's western border (production in Yamburg)

In terms of overall emissions, it was shown that the total greenhouse gas emissions from production and processing in Yamburg and from underground storage and transmission to Russia's western frontier – i.e. the methane emissions expressed as CO_2 equivalent plus CO_2 and converted N_2O emissions from turbines and power supply – are with very high probability between 7.2 t CO_2 equivalent/TJ and 12.4 t CO_2 equivalent/TJ. The mean is of the order of 8.7 t CO_2 equivalent per TJ based on the lower calorific value of the natural gas. This puts the direct greenhouse gas emissions from the combustion of natural gas, at approx. 56 t CO_2 equivalent/TJ, several times higher than the indirect emissions associated with the supply of gas from Russia.

6 Greenhouse gas emissions of fossil fuels in Germany compared

The greenhouse gas emissions of fossil fuels on the German market are made up of the direct emissions from combustion and the indirect emissions due to the supply of fuels to the German border and/or customer within Germany. While the direct emissions are largely predetermined by the chemical structure of the fuel, the indirect emissions can vary widely depending on the fuel's source. Figure 10 takes up the debate referred to in Chapter 1 about the climate compatibility of fossil fuels. In Chapter 1 it was said that the current debate centres mainly on the issue of the level of supply-related indirect emissions occurring in Russia.

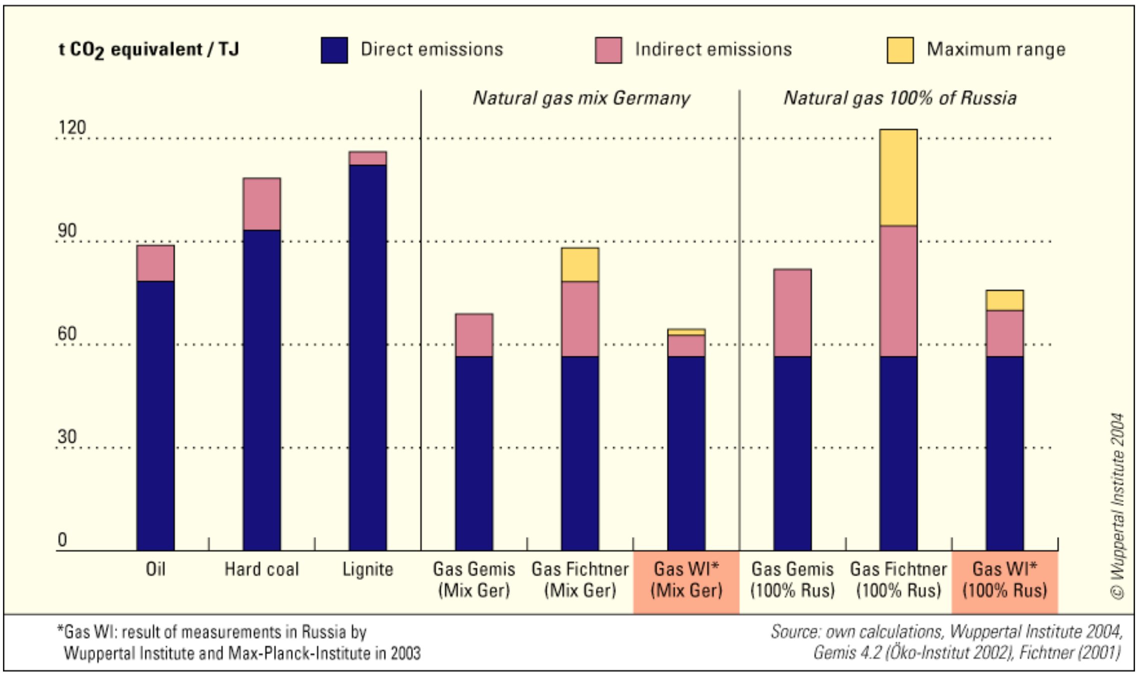


Figure 10: Direct and indirect greenhouse gas emissions from the combustion of fossil fuels – A study comparison

The figure compares three different studies for natural gas. These are, first, figures from a current GEMIS version of the Öko-Institute (Gemis 2002), second, figures from the Fichtner study of 2001, and finally the figures calculated from the measurements taken in Russia as described in the previous chapters [31]. We compared the results for natural gas that is sourced wholly from Russia, and the results for the mix in Germany, consisting of approx. 31 % Russian, 25 % Norwegian, 19 % Dutch, 18 % German gas and some 7 % from Denmark and UK.

[31] The emissions from crossing the Ukraine, Slovakia and the Czech Republic to Waidhaus (2,180 km) and through Belarus and Poland to Frankfurt/Oder (1,240 km) have been added to the emissions from gas production, processing and transmission in Russia itself. The emissions from these pipelines and compressor stations have been calculated using the characteristic values for the Russian export network. The transit through the Ukraine also includes pro rata emissions from the storage capacities of approx. 5 to 7 billion m^3 that are used by Gazprom in Western Ukraine.

The measurements carried out in the current campaign and the detailed analyses of indirect emissions of the Russian gas used in Germany result in a level of greenhouse gas emissions of 13.4 t CO_2 equivalent/TJ. The bandwidth for this figure ranges from 11.1 to 19.1 t CO_2 equivalent/TJ. This means that even if we take the upper end of the uncertainty margin as our basis, we can conclude that the indirect emissions of Russian natural gas have to be assessed as being lower than is the case in the current Gemis figures. Based on the mean value, this gives a reduction of the emission characteristic of some 40 %[32] compared with Gemis.

Table 7: Indirect greenhouse gas emissions of Russian natural gas delivered to the German border

	CO_2	CH_4		Total **)
	t/TJ	t/TJ	t CO_2 eq./TJ *)	t CO_2 eq./TJ
Lower limit	7.8	0.12	2.6	11.1
Mean	**8.7**	**0.20**	**4.3**	**13.4**
Upper limit	9.7	0.46	9.7	19.1
For information only Gemis 4.2 ****)	13.6	0.39	8.2	22.8 ***)

*) Conversion factor: 21; **) includes emissions of N_2O, total range is smaller than sum of individual uncertainty ranges; ***) CH_4 emissions calculated with a greenhouse gas potential of 23 (if a factor of 21 were used, the value would be approx. 22.1 t/TJ); ****) Figures are gas supplied to power station

Sources: Own calculations, Wuppertal Institute 2004, Fritsche 2003

Based on the natural gas mix supplied to Germany with its different source countries, and taking into account our new results for the Russian leg of the supply chain, the emission factor for indirect emissions from the supply chain is approx. 6.2 t CO_2 equivalent/TJ compared with approx. 10 t/TJ in Gemis. The emission factor confirmed in our study is therefore significantly below the data in the study by Fichtner (Fichtner 2001).

Compared with the other fuels, it would appear that the level of indirect emissions from Russian gas lies between the corresponding characteristic values for coal and oil used in Germany. Based on the gas mix used in Germany, as well as having the lowest direct emissions, natural gas also has the second lowest indirect emissions after lignite.

The results presented show that the total of greenhouse gas emissions – based on the energy content of the fuels – is on average some 18 % lower than with oil even with 100 % imports of natural gas from Russia. Compared with hard coal and lignite, the benefits in favour of Russian gas are more than 30 % and 35 % respectively. If we take the gas mix used in Germany as a realistic basis and bear in mind that use of natural gas is more efficient than coal or oil in most applications, we can see that natural gas has an even clearer competitive advantage over the other fossil fuels in terms of the greenhouse balance.

[32] It should be remembered that Gemis calculates CH_4 emissions with the higher greenhouse gas potential of 23 and also allows for the relatively low emissions from distribution in Germany (approx. 0.3 to 3.3 t/TJ according to application).

7 Summary and conclusions

Background

The anthropogenic greenhouse effect became a central issue on the energy and environmental policy agenda of the world community in the early nineties. And, in this context, there is also the question of greenhouse gas emissions in the Russian gas industry. For Germany and the EU, this question is particularly relevant in the context of a climate protection strategy that favours the increased use of natural gas. Should it emerge that the emissions associated with the energy required to transport natural gas from Western Siberia, as well as the CH_4 emissions from leaks, almost totally outweigh the benefits of natural gas with respect to the direct emissions associated with its use, increased reliance on natural gas in a climate strategy would at least be questionable.

Aside from a Russian worst-case assessment (Rabchuk et al. 1991), most statements made in the first half of the nineties on methane emissions from the Russian natural gas export system were based on speculative assumptions. Even 'losses' reported in Russian data, which included the fuel gas used as drive energy, were equated with CH_4 emissions in some cases. After it is used in the turbines this fuel gas is emitted in the form of CO_2 and has a significantly lower global warming potential (cf. Dedikov et al. 1999).

It was against this background that emission measurements were conducted on the Gazprom gas transmission network as early as the mid-nineties. Measurements were made in 1995 by the US Environmental Protection Agency (US-EPA) at four compressor stations in Central and Southern Russia[33] and in 1996/97 by Ruhrgas AG at 2 compressor stations and their associated pipeline sections in Western Siberia, on a section of pipeline in the Volga region and on the production and processing systems of the Yamburg field (Ob river estuary) currently supplying gas to the German market.

The results of the US/Russian and German/Russian measurements were of comparable orders of magnitude (Popov 2001). Both studies put the CH_4 emissions from the Russian gas transmission network at approx. 1 % of the natural gas produced. These results suggested significantly lower emissions than had previously been assumed in many cases.

Doubts were also expressed about the reliability of the measurement results. The main criticism was that the measurements could only cover a small part of the total Gazprom system and that it was not possible to verify the results as detailed information had only been published in part[34]. There were also calls for uncertainty to be analysed more accurately, the activity data used to be disclosed, and specific emission factors for individual technical components to be determined (cf. also Popov 2001 and Wuppertal

[33] The detailed results of the measurements were never published officially and so cannot be cited here.

[34] This information is basically contained in internal documentation (Ramm 1997, Kaesler, Ramm, Jansen, 1997) and was made available to the Wuppertal Institute for evaluation (Wuppertal Institute 2003, results published in Lechtenböhmer et al. 2003).

Institute 2003). Finally, the Ruhrgas results at least were criticised for having been compiled by the gas industry itself with no independent review[35].

New Independent Measurements in Russia To respond to these points of criticism and substantially improve knowledge of the emissions situation in the Russian gas export grid, Ruhrgas AG commissioned the Wuppertal Institute and the Max Planck Institute for Chemistry to devise and perform new measurements in Russia and to extrapolate the results obtained.

With technical and logistical assistance from Ruhrgas, Gazprom, the VNIIGaz Institute and the respective transmission companies, the institutes made three measurement trips to Central and Northern Russia and Western Siberia for this purpose. During the course of these visits, emissions were measured at five compressor stations along the central and northern export corridors, i.e. specifically on 50 compressors, 25 valve nodes and 2380 km of associated pipeline. The institutes also collected extensive operational data about the stations visited.

In addition, VNIIGaz/Gazprom (2004) made available detailed data on the plant and equipment installed on the export corridors, machine operating hours, characteristic emission values, repairs and maintenance, breakdowns etc., which were used for differentiated extrapolations of measurement data in line with international standards.

Result

Overall, the new measurements and calculations confirmed that the CH_4 emissions from the Russian natural gas export network are at approx. 0.7 % of the natural gas arriving at the Russia’s western border. They emit during production, processing, transport and storage and are somewhat below the level found by previous measurements. Due to Gazprom's numerous technical and organisational measures since the mid-nineties these emissions have clearly decreased in some areas. The main sources of emissions are primarily leaks or discharges from machines and valves in compressor stations for technical reasons and – to a lesser extent – due to leaks from pipeline valves. Gas venting for maintenance and repairs and emissions due to breakdowns are of lesser importance. The Monte Carlo method was used to determine the confidence interval for the CH_4 emission value. It found that emissions fall within the range from 0.4 to 1.6 % of the exported gas with 95 % certainty.

Based on gas supplies to Germany – i.e. including gas transmission outside Russia – the characteristic emission value is approx. 1 % of the natural gas arriving at Germany’s eastern border, varying over a range from 0.6 to 2.4 %. Also, with Russian natural gas just as with natural gas from other sources, the comparatively low emissions from distribution and use in Germany must be taken into consideration.

However, the methane emissions from leaks and gas venting for technical reasons are not the only critical point in a climate policy assessment, but, above all, also the transportation energy required for the long distance of approx. 4,300 km (Northern Corridor) or approx. 5,500 km (Central Corridor) from Western Siberia to Germany[36]. The CO_2 emissions associated with the fuel gas consumed by the gas turbines used

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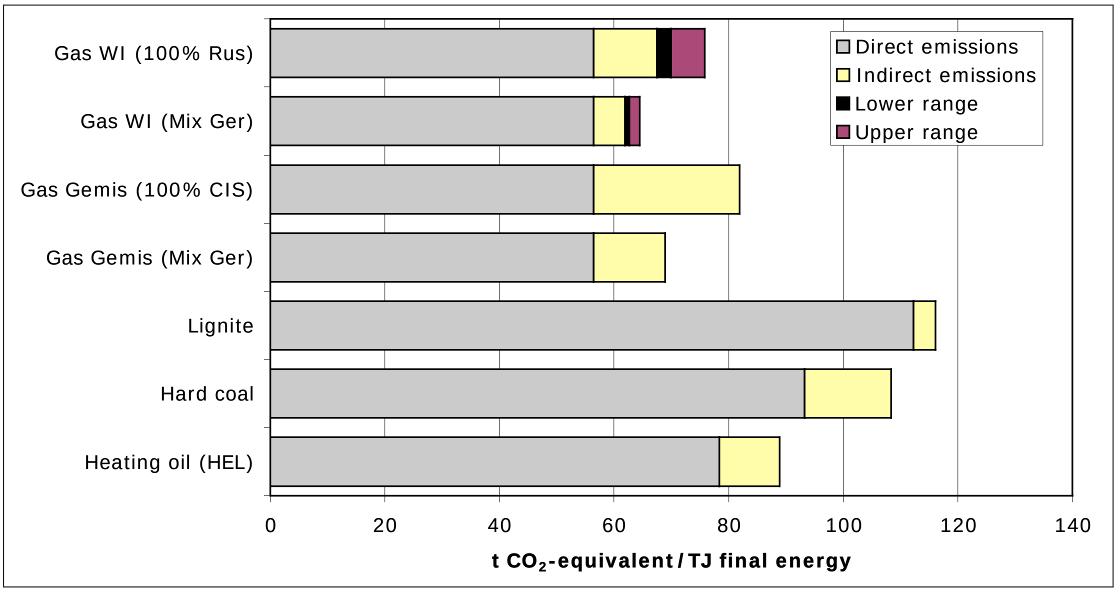
[35] This does not apply to the measurements in Yamburg in which Dr. Zittel of the Ludwig Bölkow Foundation, Munich, participated as an independent expert.

[36] The distances stated include transit distances outside Russia to the German border.

for transmission and the power required for driving the electric motors account for a total of approx. two-thirds of all greenhouse gas emissions involved in bringing Russian natural gas to the German market. The CO_2 emissions are thus twice the quantity of the CH_4 emissions (in CO_2-equivalent).

Conclusion

Overall, with the results of the analyses conducted by the Wuppertal Institute together with the Max Planck Institute for Chemistry from 2002 to 2004, new and quality-assured data for the emissions from the Russian gas export system are now available and founded on a broader empirical basis. These results were determined according to international specifications of the IPCC[37] and the US Environmental Protection Agency, and extrapolated based on the plant and equipment actually installed. With comprehensive Monte Carlo simulation calculations, it is possible to make a reliable statement in terms of methodology and data quality as to result probability and confidence intervals. More emission measurements on the Russian gas export grid should be made to further improve data reliability, and therefore, for example, data from future joint implementation projects in the field of greenhouse gas emission reduction at Gazprom should be analysed.



Source: Gemis 4.12; own calculation Wuppertal Institute, 2004

Figure 11: Greenhouse gas emissions for fuels on the German market compared

The results presented here confirm the favourable position of natural gas with respect to its greenhouse gas emissions including the natural gas imported from Russia to Germany or to the EU (cf. Fig. 11). Two thirds of the indirect greenhouse gas emissions associated with natural gas imported from Russia are attributable to CO_2 and only approx. one third to methane emissions. Overall, they are approximately of the same order of magnitude as those for oil and hard coal.

[37] Intergovernmental Panel on Climate Change

All in all, and based on the total greenhouse gas emissions for fuels, the natural gas used in Germany has a clear advantage of more than 25 % over oil as the next fuel. Even if the gas were assumed to be 100 % imported from Russia, its total GHG-emissions would have an approx. 18 % lower emission characteristic than oil in terms of energy delivered to customers in Germany. If we also factor in the greater efficiency in the use of natural gas in space heating and power generation, natural gas has an even greater advantage over the other fossil fuels in terms of greenhouse gas emissions.

Emissions from the Russian export network are also likely to fall further in future as Gazprom implement additional emission reduction measures that will be supported, inter alia, by Joint Implementation projects under the Kyoto Protocol of the UN Framework Convention on Climate Change. Moreover, the results only reflect the status quo. Any future changes in production structures or transmission paths as well as dynamic changes in the process chains of oil and coal would have to be reflected in any assessment of future developments.

Natural gas is thus the fossil fuel with the lowest greenhouse gas emissions by far. Increasing the share of natural gas in energy consumption is thus a readily available option for reducing greenhouse gas emissions as part of a climate protection strategy. Switching to natural gas can supplement the climate change policy of increasing energy efficiency substantially and switching to renewable energy sources.

8 Photo documentation

Photo 1:

Typical view on the plant area of a compressor station with compressor machines (left), gas coolers (right) and fuel gas preparation units (right ahead).

Kursk, May 2003

Photo 2:

Scrubbers/separators of a compressor station.

Kursk, May 2003

Photo 3:

Intersection valve of a pipeline; it is installed every 15 to 30 km at the long-distance transport system.

Photo 4:

Gas coolers of a compressor station.

Davidovskaja, May 2003.

Photo 5:

Vent screening.

Davidovskaja May, 2003

Photo 6:

Measurement by means of thermo-anemometer.

Photo 7:

Valve screening with Jansky detector.

Photo 8:

Valve screening with GfG-unit.

Photo 9:

Volume measurement at a fuel gas preparation unit.

Kursk, May 2003.

Photo 10:

Volume measurement at a gate valve

Uchta, June 2003.

Photo 11:

Primary data survey by measurement team.

Photo 12:

Record check by measurement team.

Photo 13:

Laser-leak-search-unit “AEROPOISK-3” for raised methan concentrations by overflight of pipeline.

Photo 14:

Laser-leak-search-unit “AEROPOISK-3” installed in a helicopter.

Photo 15:

Length of pipeline; air-borne view during an overflight by helicopter for measurement of raised methan concentrations

9 Documentation of results

The measurements, calculations and results presented here in compact form have been fully documented. Care was taken to ensure that all data were documented over the entire course of the survey and that they are also fully traceable after the event.

However because the documentation contains extensive and in part very detailed operational data that were supplied by Gazprom who classify them as confidential, it is not available for publication.

The following documentation reports exist:

Report 1: Documentation of measurements

Report 2: Documentation of measuring methods and quality assurance of the measurements

Report 3: Documentation of the raw data

Report 4: Statistical analysis of results

Report 5: Documentation of operating and plant data

Report 6: Extrapolation methodology and the Monte-Carlo method

Report 7: Quality assurance concept and project manual

Report 8: Description of the Monte-Carlo model for uncertainty analysis

Table 8: Characteristics for emission extrapolation

Efficiency		
Gas turbines	%	24 - 28
Electric machines	%	88 - 92
Emission factor of the power supply (Russian electricity grid according to Gemis)		
CO_2	g/kWh	626.8
CH_4	g/kWh	4.761
N_2O	g/kWh	0.027
Characteristic values of Russian natural gas		
Energy content at 0°C (lower calorific value)	kWh/m^3	10.01
Standard density at 0°C	kg/m^3	0.73
CO_2 equivalence factors (over 100 years)		
CH_4 (methane)	kg CO_2 eq./kg	21
N_2O (nitrous oxide)	kg CO_2 eq./kg	310

Sources: Wuppertal Institute 2003, Gazprom/VNIIGaz 2004, Öko-Institut 2002; IPCC 1995

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