

# Gasum Oy

## Environmental impacts of natural gas lifecycle from Russia to Finland



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## TABLE OF CONTENTS

<b>TABLE OF CONTENTS</b> .....	<b>3</b>
<b>TERMS AND ABBREVIATIONS</b> .....	<b>4</b>
<b>SUMMARY</b> .....	<b>6</b>
<b>1 INTRODUCTION</b> .....	<b>7</b>
1.1 OVERVIEW OF THE STUDY .....	7
1.2 WHAT IS NATURAL GAS .....	7
1.3 OPERATORS IN THE NATURAL GAS SUPPLY CHAIN.....	8
1.3.1 <i>Gasum Oy</i> .....	8
1.3.2 <i>Gazprom</i> .....	8
1.4 THE ROLE OF NATURAL GAS IN ENERGY PRODUCTION IN FINLAND, EUROPE AND GLOBALLY .....	9
1.4.1 <i>Natural gas market in Finland</i> .....	9
1.4.2 <i>Use of natural gas in Finland</i> .....	9
1.4.3 <i>Use of natural gas globally</i> .....	10
<b>2 THE SUPPLY CHAIN OF NATURAL GAS FROM RUSSIA TO FINLAND</b> .....	<b>12</b>
2.1 PRODUCTION IN RUSSIA .....	12
2.2 TRANSMISSION FROM RUSSIA TO FINLAND.....	13
2.3 TRANSMISSION IN FINLAND .....	14
2.4 USE OF NATURAL GAS IN FINLAND .....	16
<b>3 CALCULATION OF AIR EMISSIONS IN THE NATURAL GAS LIFECYCLE AND IMPACT ASSESSMENT</b> .....	<b>17</b>
3.1 GENERAL CALCULATION RULES OF THE ASSESSMENT .....	17
3.2 AIR EMISSION SOURCES.....	17
3.3 GREENHOUSE GASES .....	18
3.3.1 <i>Methodology of the assessment</i> .....	18
3.3.2 <i>Results</i> .....	19
3.4 NITROGEN OXIDE EMISSIONS.....	20
3.4.1 <i>Assessment methodology</i> .....	20
3.4.2 <i>Results</i> .....	20
3.5 SULPHUR DIOXIDE EMISSIONS .....	21
3.5.1 <i>Assessment methodology</i> .....	22
3.5.2 <i>Results</i> .....	22
3.6 IMPACTS ON AIR QUALITY AND CLIMATE CHANGE.....	22
<b>4 OTHER ENVIRONMENTAL IMPACTS OF THE NATURAL GAS LIFECYCLE</b> .....	<b>24</b>
4.1 ASSESSMENT METHODOLOGY .....	24
4.2 BIODIVERSITY .....	25
4.3 NATURAL RESOURCES.....	26
4.4 SOIL AND WATER QUALITY.....	26
4.5 LAND USE AND LANDSCAPE .....	27
4.6 NOISE AND VIBRATION .....	28
4.7 WASTE MANAGEMENT.....	29
4.8 POTENTIAL IMPACTS OF ACCIDENTS OR OPERATIONAL MALFUNCTIONS .....	30
<b>5 UNCERTAINTIES</b> .....	<b>31</b>
<b>6 COMPARISON TO SIMILAR STUDIES</b> .....	<b>32</b>
<b>7 CONCLUSIONS</b> .....	<b>33</b>
<b>8 REFERENCES</b> .....	<b>35</b>

## TERMS AND ABBREVIATIONS

ABBREVIATION	DESCRIPTION
AR5	IPCC Fifth Assessment Report
CCS	Carbon Capture and Storage
CH <sub>4</sub>	Methane
CHP	Combined Heat and Power
CO <sub>2</sub>	Carbon dioxide
CO <sub>2</sub> e	Carbon dioxide equivalent, all greenhouse gases combined and presented as a CO <sub>2</sub> equivalent unit (used in measuring the global warming potential)
dB(A)	Unit that describes the relative loudness of sounds in air as perceived by the human ear
DN100	DN refers to diameter nominal
GHG	Greenhouse gas
Hydrocarbon	Referring to all components that result from fossil sources and consist of carbon and hydrogen molecules
Hydraulic fracturing	A method used in the oil and gas industry. It means pumping a fluid mixture of water and possible chemical additives into a well. It is used in cleaning wellbores as well as to unlock oil or gas from bedrock.
IPCC	Intergovernmental Panel on Climate Change
In situ	Referring to in situ soil remediation (method where remediation masses are not excavated but instead treated on site)
Lifecycle inventory (LCI)	Part of lifecycle assessment (LCA) in which the data, input and outputs are determined, same as greenhouse gas inventory
LNG	Liquefied Natural gas
Lower calorific value	Same as net calorific value
Methane slip	Means unburned methane release from operation
Mtoe	Million oil equivalent tonnes
NGV	Natural Gas Vehicle
NO <sub>x</sub>	Nitrogen oxides (NO, NO <sub>2</sub> )
Right-of-way	Area in which construction machinery and excavation masses are located
SO <sub>2</sub>	Sulphur dioxide

THT	Tetrahydrothiophene (C <sub>4</sub> H <sub>8</sub> S), a chemical used to odorize natural gas
Transmission network	Refers to the complete infrastructure for natural gas transportation
TCF	Trillion cubic feet (unit of volume used in the United States, 1 cubic foot = 0.0283 m <sup>3</sup> ). The American term trillion means 1,000,000,000,000 (10 <sup>12</sup> )
Trunk pipeline	Same as 'transmission pipeline'. The term is used for pipelines that are larger in diameter and transport crude oil and natural gas across countries.
TSO	Transmission System Operator
TJ, MJ	Tera joule, Mega Joule (energy unit within the SI system)
TWh, MWh	Terawatt hour, megawatt hour (energy unit)
UGS	Underground Gas Storage
UGSS	Unified Gas Supply System

## SUMMARY

The aim of this report is to present the environmental impacts of the natural gas supply chain from Russia to Finland. Environmental impacts considered were biodiversity, natural resources, soil and water quality, land use and landscape, air quality and climate change, noise and vibration, waste management, and potential impacts of accidents or operational faults. In the air emission calculations, greenhouse gases (GHG), nitrogen oxide emissions (NO<sub>x</sub>) and sulphur dioxide emissions (SO<sub>2</sub>) were studied, and the greenhouse gas impact of natural gas lifecycle was evaluated.

The scope of this study includes natural gas production in Russia, transmission from Russia to Finland, transmission within Finland as well as the end use of natural gas in Finland. Decommissioning of the natural gas operations or infrastructure was not assessed in this study.

To compile this study, the environmental impacts of the lifecycle were assessed in the form of an expert assessment based on publicly available information and experience of similar environmental impact assessment projects. The initial data for natural gas network operations in Finland was obtained from Gasum. Data regarding Russian operations was obtained from Gazprom's Environmental Report 2018 and their official website.

Natural gas is a non-renewable fuel and hydrocarbon gas mixture that consists mainly of methane (CH<sub>4</sub>). The gas composition varies depending on the natural gas reserve. In the methodology used in this study, the total amount of greenhouse gases was determined, and the carbon dioxide and methane were reported separately from the total amount of GHGs. The result of the GHG inventory is presented as CO<sub>2</sub> equivalents (CO<sub>2e</sub>).

Natural gas is used for heating, electricity generation and combined heat and power production as well as for cooking, vehicle fuel and industrial processes. Although the use of natural gas has increased in transport, the total use has been decreasing in Finland during the 2000s. Even though natural gas is more environmentally friendly than other fossil fuels in terms of climate impact, low taxation of other fossil fuels, low emission allowance prices and the low price of coal has affected the use of natural gas, especially in energy production, in recent years. In 2018 and 2019, the use of natural gas increased.

Based on this expert study of the natural gas supply chain, the most significant environmental impacts arise from the use (combustion) of natural gas and the total air emissions (mostly methane) during natural gas delivery because methane is a strong greenhouse gas. The most significant issues also include alteration to land and vegetation, although these impacts are equivalent to normal construction work. Another significant impact is the utilization of natural resources in general and waste processing procedures in Russia. However, due to the mature technology of natural gas production and transmission, the lifecycle environmental impacts are well known and manageable, when the best available technology is used.

The greenhouse gas (GHG) inventory for the natural gas lifecycle in 2018 totaled about 69 gCO<sub>2e</sub> per MJ. Methane emissions accounted for just 3% of the total amount of GHG emissions. Most of the GHG emissions occur during the consumption phase in Finland (55 gCO<sub>2e</sub> per MJ). The second highest GHG emissions were in production and transmission in Russia (11 gCO<sub>2e</sub> per MJ). Transmission in Finland released only 0.2 kg CO<sub>2e</sub> per MJ.

# 1 INTRODUCTION

## 1.1 Overview of the study

Natural gas supplied to Finland is produced in Gazprom's West Siberian gas fields (Yamal, Yamburg & Urengoy), which are located around 3,300 km from the Finnish-Russian border. In Finland, Gasum Oy is responsible for the operation of gas transmission network until the end of 2019. From the beginning of 2020, transmission system operations will be unbundled from Gasum into a separate company, Gasgrid Finland Oy. In Finland, natural gas is transported via the gas transmission network and is sold to power plants, local gas distribution companies, industrial and consumer customers as well as for transport fuel.

The aim of this report is to present the environmental impacts of the natural gas lifecycle from Russia to Finland. The main environmental impacts of the natural gas supply chain are assessed taking into consideration natural gas production in Russia, transmission from Russia to Finland, transmission within Finland as well as the end use of natural gas in Finland.

The air emissions of natural gas lifecycle were calculated. Greenhouse gases, nitrogen oxide emissions and sulphur dioxide emissions were studied and air quality and climate impacts of the natural gas lifecycle were evaluated. Also, other environmental impacts were assessed including; biodiversity; soil and groundwater; noise and vibration; waste management; utilization of natural resources as well the impacts of accidents and exceptional situations.

The environmental impacts of the lifecycle were assessed in the form of an expert assessment based on publicly available information and experience of similar environmental impact assessment projects. The initial data for Finnish natural gas network operations was obtained from Gasum and data regarding Russian operations was obtained from Gazprom's Environmental Report 2018 and their official website. The environmental impact assessment was compiled by Pöyry Finland Oy.

Before this study, similar studies were carried out in 2011, 2014 and 2015:

- Neste Jacobs Oy 2015. Venäjältä Suomeen tuodun maakaasun toimitusketjun ympäristövaikutukset. 23.11.2015. Projektinumero MODA5.
- Neste Jacobs Oy 2014. Venäjältä Suomeen tuodun maakaasun tuotanto- ja käyttöketjun ympäristövaikutukset. 10.3.2014.
- Ruonakoski, Tuomas 2011. Suomeen tuotavan maakaasun polttoaineketjun kasvihuonekaasupäästöt. Aalto-yliopiston julkaisusarja TIEDE+TEKNOLOGIA 9/2011.

## 1.2 What is natural gas

Natural gas is a non-renewable fuel and hydrocarbon gas mixture that consists mainly of methane (CH<sub>4</sub>). The gas composition varies depending on the natural gas reserve. It is a naturally occurring fossil fuel and formed deep beneath the earth's surface. The natural gas composition transported to Finland is (average from 2017 to 2019):

- Methane 96.8%
- Ethane 2%
- Propane 0.3%
- Butane 0.1%

- Nitrogen 0.6%
- Carbon dioxide 0.2% (*Gasum 2019*)

The fuel density is approximately 0.72 kilograms per cubic meter and the lower calorific value is 36.4 MJ per cubic meter. When natural gas burns, it produces mostly carbon dioxide (55.3 g/MJ), water vapor and nitrogen oxides (NO<sub>x</sub>). (*Finnish Gas Association 2014 and Statistics Finland 2019*)

Methane is not classified as an environmentally hazardous chemical but as an extremely flammable gas (*ECHA 2019*).

Natural gas is most commonly used as a combustion fuel for energy generation but it is also used for cooking, as a vehicle fuel and in industrial processes. It is an ingredient of many chemicals including methanol, ammonia, hydrogen, etc. (*Finnish Gas Association 2019*)

Natural gas can be used as a fuel also in liquefied form (liquefied natural gas, LNG). LNG is formed when natural gas is cooled to -162°C. This shrinks the gas by 600 times in volume. Once liquefied, the gas can be transported by sea, road or rail to new markets.

Finland does not have any indigenous natural gas reserves.

## 1.3 Operators in the natural gas supply chain

### 1.3.1 Gasum Oy

Gasum Oy is owned entirely by the Finnish state and operates in the natural gas, biogas, recycled nutrients and LNG markets in the Nordics. Until the end of 2019, Gasum Oy is also the transmission system operator (TSO) and natural gas is transported to Finland from a single point (Russia). Gasum Oy is also the leading supplier of biogas and liquefied natural gas (LNG) in the Nordic countries. The company's revenue in 2018 was €1,177 million. The company employs approximately 400 people in Finland, Norway and Sweden. (*Gasum Oy 2019b*)

Gasum Oy operates under certified management systems, ISO 9001 quality management system, ISO 14001 environmental management system, ISO 50001 energy efficiency system and OHSAS 18001 occupational health and safety system.

### 1.3.2 Gazprom

Gazprom (the Public Joint Stock Company Gazprom or PJSC Gazprom) is a Russian oil & gas enterprise. Gazprom is the largest company in Russia and the world's largest producer of natural gas. Besides natural gas, the company also produces gas condensate and oil, sells gas as a vehicle fuel and generates and markets heat and electric power. The term Gazprom or Gazprom Group refers to the parent company and all its subsidiaries. (*Gazprom 2019a and 2018*)

Gazprom holds the largest natural gas reserves in the world (16% of the world's natural gas reserves and 69% of Russia's gas reserves). In 2018, Gazprom produced approximately 499 billion cubic meters of natural and associated gas, 15.9 million tonnes of gas condensate and 48 million tonnes of oil. Gazprom's gas production regions include the Yamal Peninsula, Eastern Siberia, the Far East, and the Russian continental shelf. The natural gas imported into Finland originates from Western Siberia (Yamal, Yamburg and Urengoy), where Gazprom has its largest natural gas production fields. (*Gazprom 2019a*)

Gazprom also operates the longest natural gas transmission network in the world, in total of 172.1 thousand kilometers. Gazprom owns the 'unified gas supply system' (UGSS)



that operates the natural gas transmission pipelines (trunk pipeline) and is responsible for its operation, maintenance and safety. The length of transmission pipelines to Finland is approximately 3,300 kilometers. Production in Urengoy started in 1978 and in Yam-burg 1991. One new natural gas field has been in pilot production in Yamal since 2012. Most of Gazprom's total natural gas production originates in Western Siberia (Ural Fed-eral District). In 2018, there were 138 natural gas fields in operation in the Russian Fed-eration. (*Gazprom 2018 and Gasum Oy 2019*)

Gazprom complies with quality and environmental management systems based on inter-national ISO standards (ISO 9001:2015 and 14001:2015). Management systems were certified in 2017. The health and safety management system is based on a corporate standard STO Gazprom 18000.1-001-2014 called "Integrated System of Occupational and Industrial Safety Management at Gazprom. Main Provisions." According to Gaz-prom, the system has been certified under OHSAS 18001:2007 since 2014.

## 1.4 The role of natural gas in energy production in Finland, Europe and glob-ally

### 1.4.1 Natural gas market in Finland

Gasum Oy is responsible for the operation of gas network in Finland (responsible trans-mission system operator, TSO) until the end of 2019. Until this point, Finland's segre-gated market and derogation from the European regulation have enabled the natural gas transmission system operator and the seller of natural gas to operate as one company. Natural gas transmission and the markets are supervised by the national Energy Author-ity.

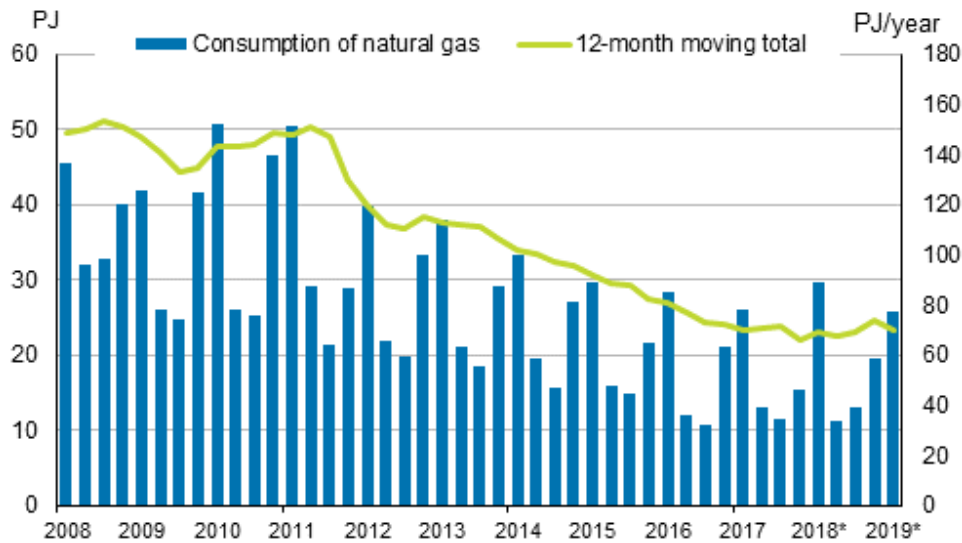
However, the Finnish natural gas market will be connected to the European natural gas network through the Baltic Connector pipeline, a natural gas transmission pipeline be-tween Finland and Estonia, from the beginning of 2020. This has ushered in a long-anticipated reform of the Finnish Natural Gas Market Act, which entered into force at the beginning of 2018 and requires a natural gas company to unbundle its natural gas net-work operations, liquefied natural gas processing facility operations, natural gas selling operations and natural gas storage from the beginning of 2020. (*Natural Gas Market Act 2019*)

Gasum Oy signed a mutual agreement to develop the natural gas markets together with Baltic Connector Oy and other TSOs from Estonia and Latvia (Elering and Conexus Bal-tic Grid) in 2018. This Memorandum of Understanding was a first step aiming to harmo-nize the forthcoming common natural gas markets. The purpose of the agreement was also to ensure the future competitiveness of natural gas for industry and transportation users in the region. In February 2019, the integration of Finland and the Baltic states' gas markets took another step forward when the companies signed an agreement re-moving the transmission tariff between country borders. Under this ITC agreement (Inter TSO Compensation), the TSOs have agreed to compensate the costs of gas transmis-sion to each other and so enable the development of open gas markets in which both traders and shippers can operate more easily. (*Gasum Oy 2019a and Baltic Connector Oy 2018*)

### 1.4.2 Use of natural gas in Finland

Natural gas is used as a source of energy primarily for heating, electricity generation and combined heat and power production. It is used also as a fuel for vehicles. In the manu-facturing industry, natural gas is used to generate, for example, process steam. In

Finland, the use of natural gas has decreased during the 2000s. The use of natural gas is presented in the following figure 1.



**Figure 1. Amount of natural gas used in Finland. Natural gas consumption increased in 2018 and 2019. (Official Statistics Finland, 2019a)**

In 2018, natural gas accounted for 5% of total energy consumption in Finland. The share has decreased significantly during the 2000s. The total amount of natural gas sold in Finland was 73,576 TJ and the latest trends show an increase of 12% in the use of natural gas compared to 2017. (*Official Statistics of Finland 2019a*)

In 2018, 14.65 TWh of natural gas was used in industry, 9.3 TWh in energy production and 0.6 TWh in heating and stoves. Natural gas used in transport was 40.3 GWh in 2018. (*Finnish Gas Association 2018 and Gasum Oy 2019*)

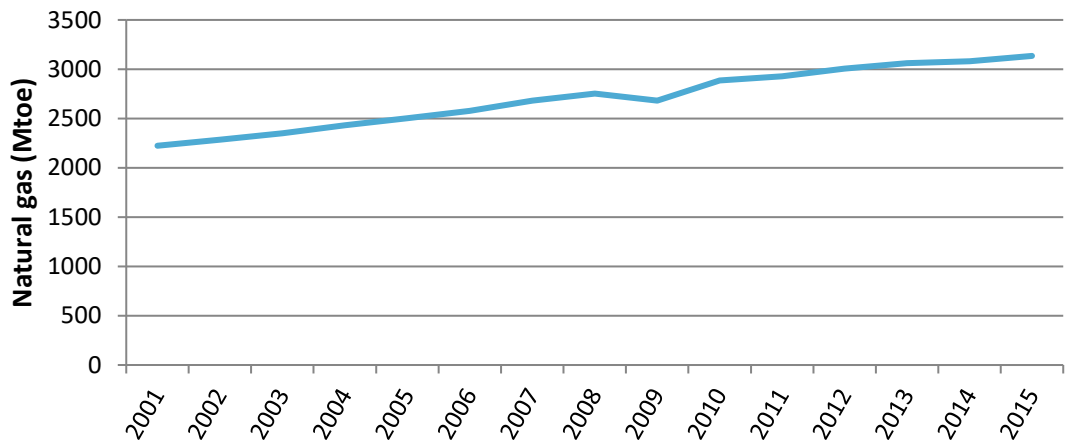
Many factors impacted the decrease in the consumption of natural gas in recent years, especially in energy production. For example, the low price of coal and the taxation of similar fuels, despite natural gas being a more environmentally friendly fuel. Also the price of emission allowances has been low.

The amounts of natural gas imported into Finland can be followed via the ENTSOG (European Network of Transmission System Operators for Gas) website.

### 1.4.3 Use of natural gas globally

Unlike in Finland, the use of natural gas globally has increased in recent years. The production and availability of natural gas has improved and the supply of liquefied natural gas has increased. The world's energy consumption is estimated to increase. The United States and Middle East are leading global natural gas production. The top five countries (United States, the Russian Federation, the Islamic Republic of Iran, Canada and Qatar) account for more than half of global gas production. (*British Petroleum 2019 and IEA 2019*)

## Natural gas consumption globally



**Figure 2. Amount of natural gas (Mtoe) used globally. (Official Statistics of Finland, 2019b)**

Consumption, especially within the transport sector, has been increasing rapidly. According to the NGV Communication Group (natural gas vehicles) in 2010 there were 11.3 million NGVs around the world, and by 2015 this figure had already reached 22.5 million. The number of natural gas vehicles in Finland has also increased significantly in 2017 and 2018 compared to previous years. According to Traficom (the Finnish Transport and Communications Agency), the number of natural gas operated vehicles was approximately 6,300 by 2018. During 2018, registrations of new natural gas vehicles almost doubled. (*Gasum 2019d and Gazprom 2015*)

## 2 THE SUPPLY CHAIN OF NATURAL GAS FROM RUSSIA TO FINLAND

The following chapter gives a general description of the natural gas supply chain from Russia to Finland. The supply chain of natural gas from Russia to the Finnish border consists of production and transmission phases. Production includes gas extraction, purification and drying. Transmission takes place via a high-pressure natural gas transmission network. Gas-fueled compressor engines compress the natural gas to high pressure for transmission through the large pipelines.

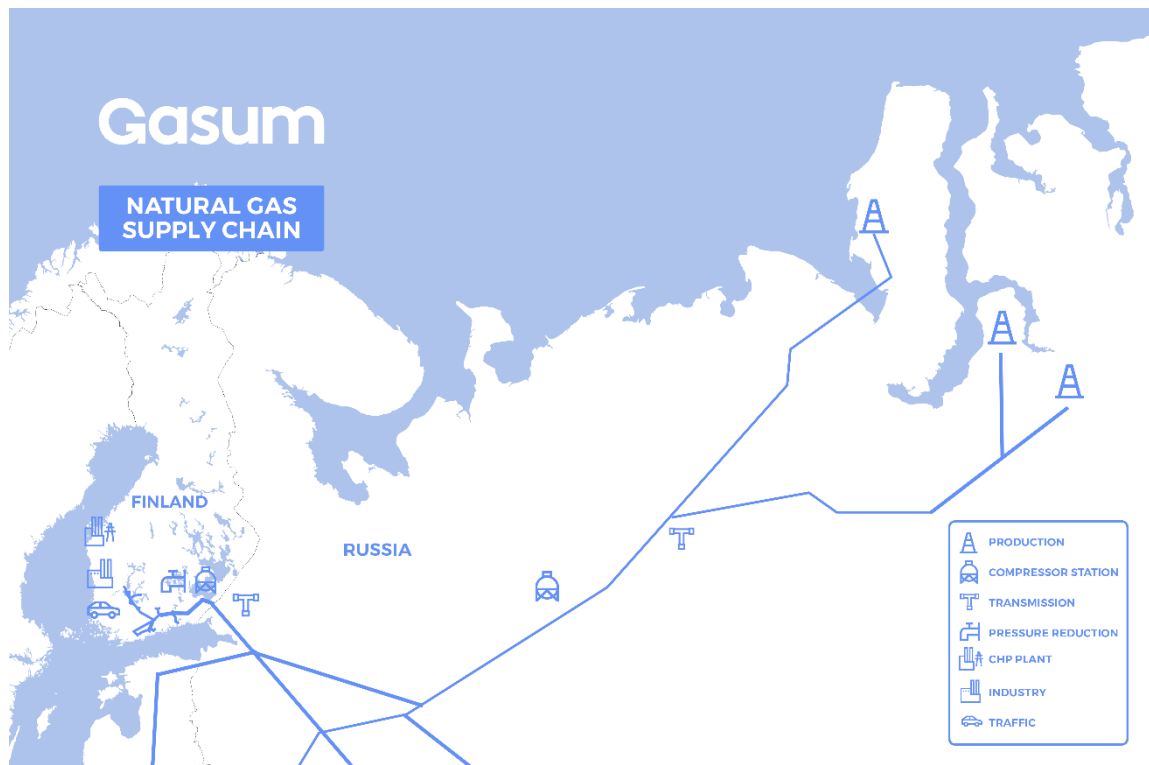


Figure 3. Natural gas supply chain from Russia to Finland. (Gasum Oy 2019)

### 2.1 Production in Russia

The natural gas supplied to Finland is produced in Gazprom’s West Siberian gas fields (Yamal, Yamburg and Urengoy), which are located around 3,300 kilometers from the Finnish-Russian border (Gasum 2019a). Gasum purchases around 2.4 billion cubic meters of natural gas from Gazprom (Gasum 2019c) each year. The volume of natural gas supplied to Finland is less than 1% of Gazprom’s total gas production.

Natural gas occurs in fine pores of underground rock formations which can range from depths of 1,000 meters to several kilometers. Gas is extracted from the subsurface using specially drilled wells called producing or operating wells. The wells can be used also for studying the geological structure of the subsurface, prospecting for new fields and supporting operations. (Gazprom 2019a)

Generally natural gas can be produced from oil wells or particularly from wells with natural gas as the main objective. Methane is the main component but natural gas includes also other significant components such as ethane, butane and propane. Heavier components like propane and butane exist as liquids when cooled and compressed, and these are often separated. (IFC 2007)

Exploration activities include seismic surveys and drilling. Permanent infrastructure is installed during the gas field development and/ or production phase. It can include drilling additional wells, central production facilities, for example for the treatment of gas, and the installation of flowlines and pipelines for gas export. *(IFC 2007)*

Natural gas rises to the surface due to its natural tendency to fill areas with the lowest pressure. Hydrocarbons generally flow freely from wells but subsurface pumps can be used for additional pressure *(IFC 2007)*. After extraction, natural gas is taken for treatment (purification and upgrading according to need). Components like hydrogen sulphide H<sub>2</sub>S and water need to be removed and the gas might also need upgrading (removal of CO<sub>2</sub>). This will create a sufficient calorific value for the gas. Natural gas is cleaned several times: right at the well outlet, in surface separators and in addition during the transmission and at compressor stations. *(Gazprom 2019a)*

The normal lifespan of a production well includes a high peak of gas production in the beginning and then gradually declining production. The gas operator can perform well workovers to clean out the wellbore (for example, acid can be used) and therefore allow the gas to flow more easily. Conventional natural gas reservoirs, such as the Siberian natural gas fields, mainly consist of large defined underground spaces. When the natural gas exists in diverse underground formations, other measures can be used. One widely used method besides cleaning the wellbore is fracturing. Fracturing technology means pumping a fluid mixture of water and possibly chemical additives into a well. The method has been used in the oil and gas industry for decades. The fluid mixture (gelled water and hydrocarbon-based liquids) combined with hydraulic pressure is used to unlock oil or gas from the bedrock and bring it to the surface. Fracking fluids (containing solid material, oil and possible additives) are generated in the method. *(IFC 2007)*

Fracturing is a method that has been used in the Yamal peninsula Siberia oil fields and is a method that Gazprom is developing. For example, coalbed methane (CBM) production may include hydraulic fracturing. Evidence of using this method in producing natural gas for Finland was not gained during this study. *(IFC 2007, 2017 and Gazprom 2019c)*

Before transportation, natural gas needs also to be dried, since moisture can damage the gas equipment and form plugs, so-called crystalline hydrates, in the pipeline. Gas is dried by running it through adsorbents or by cooling the gas stream. Gas condensate, which is separated from natural gas, can be utilized in the same way as crude oil for refining, for example for the production of fuels or plastics. *(Gazprom 2019a)*

Gazprom has developed natural gas production particularly in the Yamal region. Eleven gas fields and 15 oil and gas condensate fields have been discovered in the Yamal Peninsula and adjacent offshore areas. Commercial operation in the Yamal natural gas fields can increase local production to up to 360 billion cubic meters annually by 2030. Therefore, the development of this production area is Gazprom's strategic interests. In December 2008, Gazprom launched their Yamal megaproject and the commissioning of the first pilot extraction field started in 2012. The development of Yamal natural gas production has included also building a 572-kilometer railroad. In 2018, Gazprom reported commissioning of the Bovanenkovskoye gas field no. 3, which is the largest of their explored reserves. *(Gazprom 2009, Gazprom 2018b)*

## 2.2 Transmission from Russia to Finland

Transmission of natural gas from production wells to Finnish customers takes place through the gas transmission system. The complete gas transmission system in Russia includes gas trunk lines (transmission pipelines), distribution pipelines, pipeline bridges, branches and infeed gas pipelines. Transmission of Gazprom's natural gas proceeds through several transmission pipelines, potential underground storage and final transmission to Finland through natural gas pipelines in the Leningrad Region. *(Gazprom*

2019a) Only onshore transmission pipelines are used in the supply of natural gas to Finland. The pipelines in Russia can be underground (at a depth of approx. 0.1–0.8 m) or above ground (supported by scaffolding).

Natural gas pipelines are constructed in a sequential process, which includes staking and clearing of the pipeline centerline and right-of-way, trenching, pipeline laying, welding, bending on site if necessary, coating welded joints, testing and backfilling of the trench. During commissioning, the pipelines are also filled with water and hydrotested. (IFC 2007)

During natural gas transmission, the pressure of the gas gradually decreases along the pipeline route. To increase the pressure again, natural gas compressor stations are used along the pipeline route. Natural gas is usually compressed to 30- max. 80 bars. High pressure also increases the transmission capacity of the pipeline network because the density of gas increases and the same amount of gas will require a smaller volume in the pipeline. Therefore, it can be said that pipeline transmission of natural gas is an efficient way of transporting fuel. Compressor stations using natural gas as a fuel are located along the pipeline at distances of approximately 100-200 kilometers.

Compression adds heat to the gas, resulting in warmer gas being discharged by the compressor. Because of this, aftercoolers are needed at compressor stations. In addition to compressing natural gas, compressor stations also usually contain some type of liquid separator to capture any liquids or other unwanted particles from the natural gas in the pipeline (drying of the gas). For example, a certain amount of water, hydrocarbons or particles can be condensed out of the gas stream while in transit.

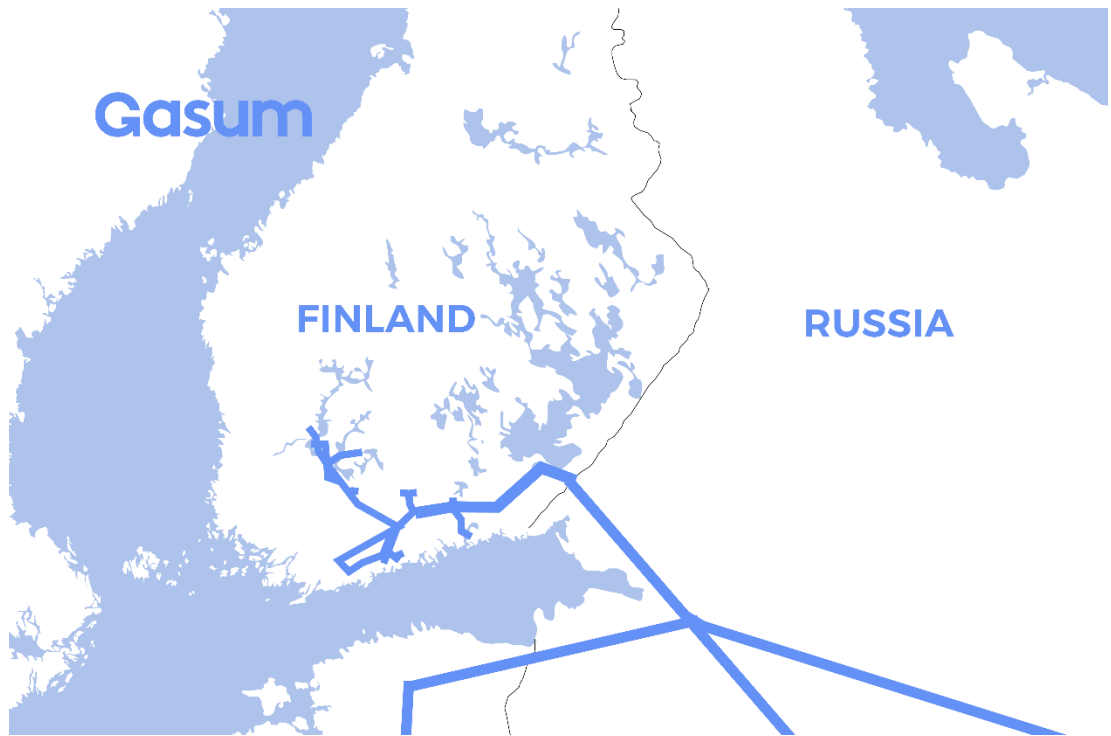
Metering stations are also used throughout the natural gas transmission system. These stations measure the flow of gas along the pipeline and allow pipeline operators to monitor the natural gas network.

While daily fluctuations in gas consumption are controlled by dispatchers, seasonal fluctuations are compensated by changing the operating conditions of the compressor station or by using mainly underground gas storage facilities (UGS). There is at least one underground storage facility for natural gas in Punginskoye along the natural gas transmission route to Finland. (Gazprom 2017)

## 2.3 Transmission in Finland

Gasum currently owns the Finnish natural gas transmission pipeline network and is responsible for natural gas transmission in Finland. Imported natural gas from Russia is transmitted across the border by two transmission pipelines. Two transmission pipelines ensures security of supply. (Gasum 2019b)

Natural gas is transmitted to Finland through a receiving/metering station in the municipality of Imatra near the Russian border in Eastern Finland where also the first compression station of Finland is located. The natural gas delivered is monitored and measured using ultrasound measuring. The metering station analyzes the composition of the imported natural gas (amount of methane and other hydrocarbons, etc.). Before analysis, the natural gas is filtered of potential waste oil or other particles. The carbon dioxide emission factor for the imported natural gas is determined based on the measurement. From the receiving station, the natural gas is transmitted to customers via the transmission and distribution pipeline network in Finland. Other compressor stations in Finland are located in Kouvola and Mäntsälä. (Gasum 2019a)



**Figure 4. Natural gas transmission network to Finland.**

The compressor stations along natural gas transmission network are used to increase gas pressure and transmission capacity in the pipeline. In addition to the compressor unit, the main equipment at the compressor station includes gas filtering, gas cooling, station valves and an automated emergency shutdown system. The Finnish compressor stations are more or less comparable to the Russian ones. Natural gas from the transmission pipeline is used as a fuel for the compressor and is combusted in the unit's gas turbine section. The hot gases created in natural gas combustion rotate the gas turbine. The exhaust gases (mainly water vapor, carbon dioxide and nitrogen oxides) are emitted into the air via an exhaust stack. (*Gasum 2019a*)

Gasum has a total of approximately 1,300 kilometers of high-pressure transmission pipelines in Finland. The pipelines are laid at a depth of at least 1 meter, and their location is marked with white signposts. The gas pressure in the existing transmission pipelines ranges from 30 to 54 bars. The pipelines are steel pipelines coated with polyethylene plastic and protected against corrosion by a cathodic protection system. The diameter of the high-pressure transmission pipelines range between DN100 and DN1000. (*Gasum 2019a*)

Along the transmission pipeline network, valve stations are located between approximately 10-30 km. Valve stations are used for monitoring and network safety. Their safety cut-off devices can be used to cut off gas transmission and distribution and, if needed, release natural gas from a pipeline section using a so-called blowdown. There are a total of 166 valve stations along the transmission network in Finland. (*Gasum 2019a*)

Gasum transmits the natural gas from the Russian border to Southern Finland via Kouvola and Mäntsälä. The natural gas transmission network is supervised remotely day and night from the central control room in Kouvola. From Mäntsälä, the transmission network continues along two routes to the Helsinki region as well as to the Tampere region.

## 2.4 Use of natural gas in Finland

The natural gas is channeled from the transmission pipelines to pressure reduction stations where the high transmission pressure is reduced to a level suitable for customers. There are 135 pressure reduction stations in the Finnish gas transmission network, and the amount of gas delivered to consumers is measured at these stations. The distribution network starts from the pressure reduction stations. (*Gasum 2019a*)

Since natural gas has no odor, it is odorized at pressure reduction stations before delivery to consumers. Odor is used to detect possible leaks in the distribution network. In Finland, natural gas is odorized using THT (tetrahydrothiophene C<sub>4</sub>H<sub>8</sub>S), which has a pungent smell.

Natural gas is used in many large cities and also in smaller municipalities along the pipeline route, including, Imatra, Lappeenranta, Kouvola, Lahti, Mäntsälä, Helsinki, Espoo, Lohja, Hyvinkää, Lempäälä and Tampere (Figure 4). (*Gasum 2019a*)

Natural gas is used in combined heat and power (CHP) production in particular. The role of natural gas is emphasized during the cold winter months, when it can be used to provide capacity for peak consumption periods. In addition to combined heat and power, various industrial processes constitute another major usage area for natural gas. (*Gasum 2019a*)

Natural gas is widely used for residential heating, but it is not a common fuel for heating single family homes. Other residential use of natural gas centers around Helsinki, where gas is used for cooking in around 20,000 homes. Natural gas is also used in many restaurants. (*Gasum 2019a*)

Natural gas use as a transport fuel has increased. There were approximately 6,300 gas-fueled vehicles on Finnish roads in 2018, and the number has risen strongly in recent years. Natural gas in consumer traffic is used in bi-fueled vehicles, which also have a small petrol tank. Liquefied natural gas is also used in heavy duty vehicles and is in fairly common use in different delivery vehicles, for example. Gasum's gas filling station network has expanded considerably in recent years and the development and building of new filling stations in Finland is an on-going activity. The highest number of filling stations can be found in southern part of Finland, where the gas transmission network also is. (*Gasum 2019a*)



### 3 CALCULATION OF AIR EMISSIONS IN THE NATURAL GAS LIFECYCLE AND IMPACT ASSESSMENT

This chapter presents the results of air emission calculations in the natural gas lifecycle. The calculation of air emissions included inventories of greenhouse gases (GHG), nitrogen oxides (NO<sub>x</sub>) and sulphur dioxide emissions (SO<sub>2</sub>). Chapter 3.2 describes the emission sources. Besides the calculation, the impacts of air emissions for air quality and climate change are assessed.

#### 3.1 General calculation rules of the assessment

In this calculation, the natural gas lifecycle included production functionalities of natural gas in Russia, transmission of natural gas from Russia to Finland, transmission of natural gas within Finland and the consumption of natural gas in Finland. The table below lists the activities included in each lifecycle stage.

**Table 1. Activities included in different stages of the natural gas lifecycle.**

Lifecycle stage	Activities included
<b>Production and transmission in Russia</b>	Production activities (including exploration), transportation, underground storage and processing hydrocarbons as well as natural gas transmission pipeline operations by the United Gas Supply System (UGSS). Additionally, the reported seven natural gas leakage accidents were included.
<b>Transmission in Finland</b>	Compressor stations, pressure reduction stations and transmission pipeline.
<b>Consumption in Finland</b>	Consumption of natural gas.

The lifecycle stage in Russia (production and transmission) is operated by Gazprom. The emission data applied was sourced from Gazprom’s Environmental Report 2018. The following lifecycle stages in Finland are operated by Gasum. The data required for lifecycle stages in Finland were provided by Gasum. Overall raw data utilized in calculation was from 2018.

Air emissions were calculated by using raw data collection and different factors. Conversion and emission factors were taken from public sources including Fuel classification 2019 (Statistics Finland), Lipasto (VTT), Motiva and the Finnish Gas Association.

#### 3.2 Air emission sources

Natural gas extraction activities, natural gas itself and its by-products release air emissions. Development of natural gas production activities produces hydrocarbons that Gazprom wants to utilize. If these hydrocarbons cannot be processed during the drilling or development of a gas well, they must be either emitted into air or more appropriately flared at site. The flaring of hydrocarbons in general produces carbon dioxides, nitrogen oxides, sulphur dioxides and particle emissions. Sulphur is usually extracted from the fuels, but extraction is most commonly done by oxidation and will therefore release

sulphur dioxide emissions. Particles and water are removed through filtering. Most of the production-related air emissions are emitted by flaring (burning) or venting. Air emissions are also produced from the production of heat or electricity on site. Heat is needed for the necessary production buildings and accommodation and if grid electricity is not available, electricity can be also produced on site. Most production areas are highly developed and therefore they have many utilities and commodities available. Air emissions are also caused by different kinds of transport activities if using fossil fuels such as natural gas, petrol or diesel fuels. Development of the natural gas pipeline network will not directly affect air emissions and emissions from the production of the pipeline and other equipment are not usually included. This study did not include calculation of air emissions from the gas infrastructure materials.

When methane is combusted and used to generate heat or electricity, it causes the least amount of carbon dioxide emissions compared to other fossil fuels (like coal or oil). Also, the energy efficiency of modern natural gas CHP (combined heat and power) units or plants is extremely good (can be above 90%). During the combustion of natural gas, methane (98%) and combustion air will produce mainly carbon dioxide and nitrogen oxides. Natural gas does not contain any nitrogen, so the amount of nitrogen emissions depends on the burner or plant characteristics. Since natural gas is treated and the naturally occurring sulphur is removed, the combustion of purified natural gas (methane approx. 98%) does not emit any sulphur dioxide emissions.

Transmission of natural gas in the pipeline network requires high pressure, which is generated by combusting natural gas at compressor stations. Compressor stations most commonly consist of gas turbine power units and the natural gas is compressed to the required pressure for transmission. Compressor stations are located along the pipeline network. The combustion of natural gas is considered in Gazprom's total GHG emissions (UGSS, the natural gas transmission operations included). Apart from the natural gas combustion at compressor stations, gas transmission itself does not cause other significant emissions into the air during normal operation.

### 3.3 Greenhouse gases

Greenhouse gases (GHG) are a group of gases that contribute to global warming. Notable GHGs are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O) and various fluorinated gases.

#### 3.3.1 Methodology of the assessment

In this methodology, the greenhouse gas calculations have been carried out reliably and transparently in accordance with international standards and accounting guidelines. The calculations applied various lifecycle standards (ISO 14040, 14044).

In the methodology of this study, the total amount of greenhouse gases was determined and carbon dioxide and methane were reported separately from the total amount of GHGs. The result of the GHG inventory is presented as CO<sub>2</sub> equivalents (CO<sub>2e</sub>).

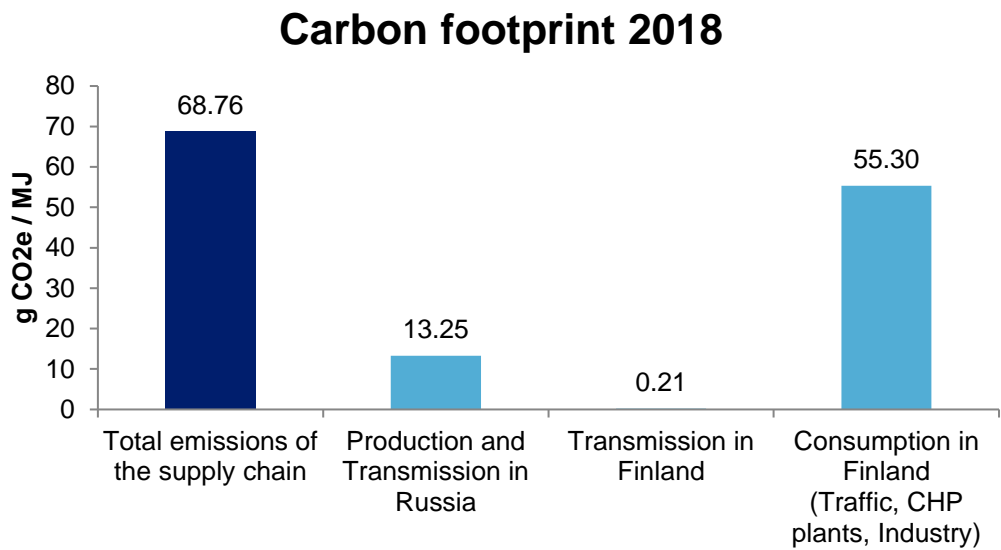
The table below lists the constants used in this calculation.

**Table 2. List of constants used in calculation.**

Item	Value	Unit
Natural gas density	0.7418	kg/m <sup>3</sup>
Natural gas energy content	36.4	GJ/1000 m <sup>3</sup>
Electricity grid mix emission factor in Finland	164	kgCO <sub>2e</sub> /MWh
Natural gas emission factor	55.3	tCO <sub>2</sub> /TJ
Methane emission factor	28	CO <sub>2e</sub>

**3.3.2 Results**

Figure 5 shows the overall results of the origin of greenhouse gases in the natural gas lifecycle. The consumption of natural gas constitutes a major impact (80%) on total greenhouse gases during the entire lifecycle. Emissions during the consumption phase arise in the use of natural gas in CHP plants, industry or transport. Production and transmission in Russia amounted to 19% and transmission in Finland to less than 1% share of total greenhouse gas emissions.



**Figure 5. Overall results of the origin of greenhouse gases in the natural gas lifecycle.**

The table below presents the results of greenhouse gas calculation. These results are shown in tonnes of CO<sub>2e</sub> and grams of CO<sub>2e</sub> per MJ of natural gas.

**Table 3. Results of greenhouse gas emissions (GHGs) through the natural gas lifecycle.**

Life cycle stage	GHGs [tonnes of CO <sub>2e</sub> ]			GHGs [grams of CO <sub>2e</sub> per MJ]		
	GHGs	CO <sub>2</sub>	CH <sub>4</sub>	GHGs	CO <sub>2</sub>	CH <sub>4</sub>
	Production and transmission in Russia	<b>1,179,545</b>	1,016,442	163,103	<b>13.25</b>	11.42
Transmission in Finland	<b>18,691</b>	10,607	8,084	<b>0.21</b>	0.12	0.09
Consumption in Finland (Transport, CHP plants, Industry)	<b>4,864,380</b>	4,864,380	0	<b>55.30</b>	55.30	0
<b>Total GHG emissions 2018</b>	<b>6,062,616</b>	5,891,430	171,186	<b>68.76</b>	66.84	1.92

### 3.4 Nitrogen oxide emissions

The amount of nitrogen oxides (NO and NO<sub>2</sub>) are given as total emissions of NO<sub>x</sub>.

#### 3.4.1 Assessment methodology

Nitrogen oxides are generated in the combustion process where nitrogen from the air binds with oxygen. Since natural gas does not contain nitrogen, nitrogen emissions are only generated in the combustion processes. Due to divergence in emissions in the consumption phase, this calculation presents three different supply chains separately.

#### 3.4.2 Results

As the following figure shows, most of the nitrogen oxide emissions are released during the consumption of natural gas in Finland, where natural gas is used in CHP plants (89%), industry (85%) and transport (56%). Production and transmission in Russia emits 11%, 15% or 44% depending on the end use and transmission in Finland accounts for less than 1% of nitrogen oxide emissions.

### Nitrogen oxide emissions 2018

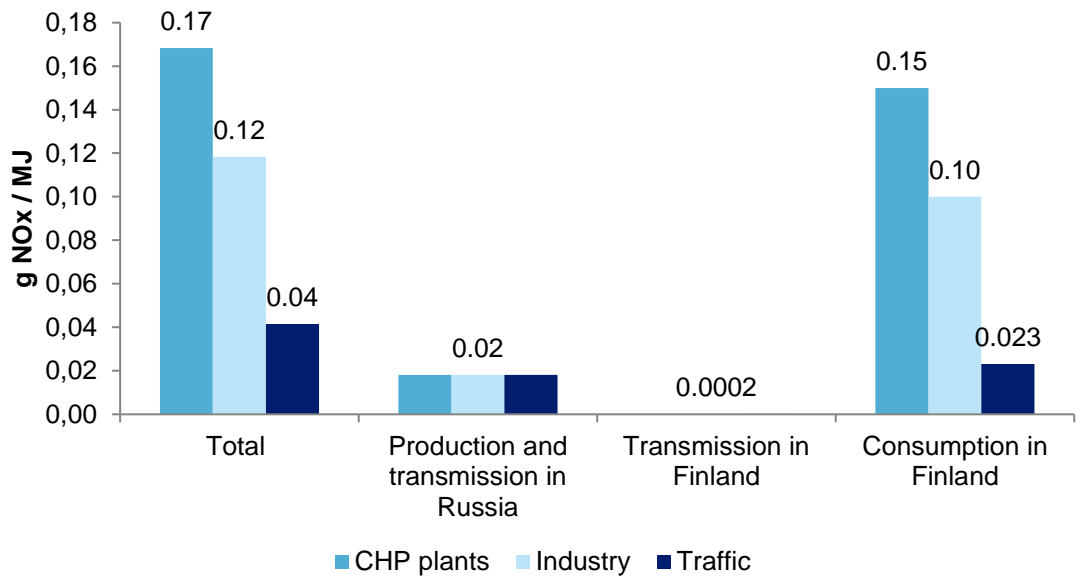


Figure 6. Overall results of nitrogen oxide emissions in the natural gas lifecycle.

The table below presents the results of nitrogen oxide emissions from 2018 as total emissions in tonnes and grams per energy unit (MJ) in each lifecycle stage.

Table 4. Results of nitrogen oxide (NO<sub>x</sub>) emissions through the natural gas lifecycle.

Lifecycle stage	Nitrogen oxide (NO <sub>x</sub> ) emissions	
	NO <sub>x</sub> [tonnes]	NO <sub>x</sub> [g/MJ]
Production and transmission in Russia	1,613	0.02
Transmission in Finland	18	0.0002
Consumption in Finland (CHP Plants)	5,383	0.15
Consumption in Finland (Industry)	5,193	0.10
Consumption in Finland (Transport)	3	0.023
<b>Total NO<sub>x</sub> emissions in 2018 (CHP Plants)</b>	<b>7,015</b>	<b>0.17</b>
<b>Total NO<sub>x</sub> emissions in 2018 (Industry)</b>	<b>6,824</b>	<b>0.12</b>
<b>Total NO<sub>x</sub> emissions in 2018 (Transport)</b>	<b>1,635</b>	<b>0.04</b>

### 3.5 Sulphur dioxide emissions

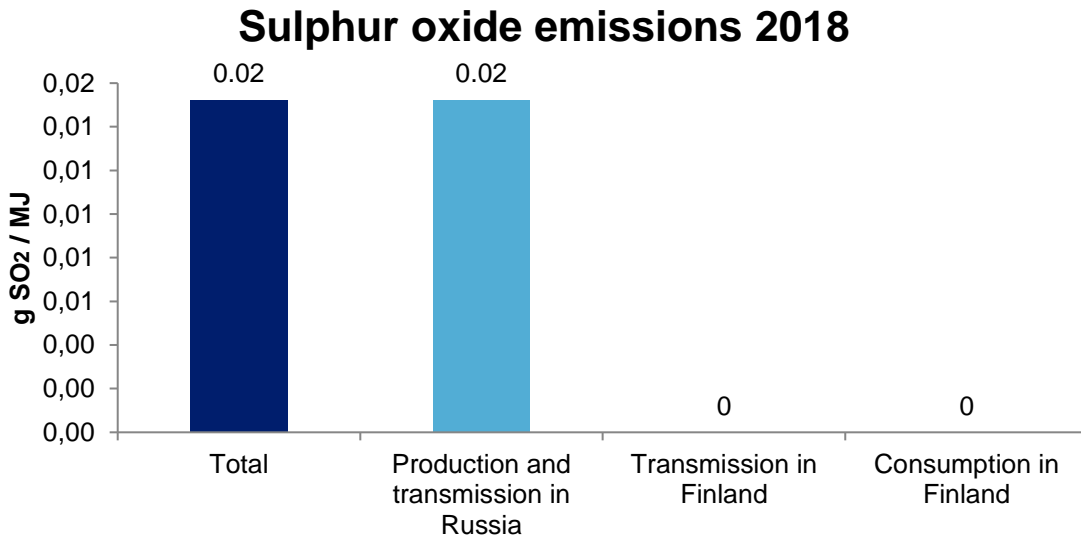
In this chapter, the results of sulphur dioxide emissions are presented. The results are presented using the unit of SO<sub>2</sub>. Sulphur exists naturally mainly as hydrogen sulfide (H<sub>2</sub>S) in natural gas and its reserves.

### 3.5.1 Assessment methodology

In the natural gas lifecycle, sulphur dioxide emissions are only released in the production process of natural gas in Russia. In the production process, sulphur is removed from natural gas generally by oxidation, which results in SO<sub>2</sub> emissions into the air.

### 3.5.2 Results

The figure below presents the overall results of sulphur dioxide emissions in 2018.



**Figure 7. Overall results of sulphur oxide emissions of natural gas lifecycle.**

As explained in the previous chapters, the main and only contributor of sulphur dioxide (SO<sub>2</sub>) emissions is the production and transmission in Russia. Natural gas should contain no sulphur after the sulphur purification process. The quality of the natural gas transmitted to Finland is monitored.

The table below presents the results of sulphur dioxide emissions in 2018 as total emissions in tonnes and grams per energy unit (MJ) in each lifecycle stage.

**Table 5. Results of sulphur dioxide (SO<sub>2</sub>) emissions through the natural gas lifecycle.**

Lifecycle stage	Sulphur dioxide (SO <sub>2</sub> ) emissions	
	SO <sub>2</sub> [tonnes]	SO <sub>2</sub> [g/MJ]
Production and transmission in Russia	1,356	0.02
Transmission in Finland	0	0
Consumption in Finland ( <i>Transport, CHP plants, Industry</i> )	0	0
<b>Total SO<sub>2</sub> emissions 2018</b>	<b>1,356</b>	<b>0.02</b>

## 3.6 Impacts on air quality and climate change

The impacts of the natural gas lifecycle on air quality can be significant from a local perspective. Total GHGs and air emissions in the oil and gas industry are significant.

Nitrogen oxide (NO<sub>x</sub>) and sulphur dioxide emissions (SO<sub>2</sub>) originate in the production process and operation of the natural gas lifecycle. These emissions impact air quality.

NO<sub>x</sub> emissions are most significant in the combustion process during natural gas transmission and particularly in end use (combustion at CHP plants, industrial applications and transport). Because the amount of these emissions depends on the combustion plant or burner properties, this study was unable to determine the exact amount of these emissions. Emission factors were used from a public source to calculate NO<sub>x</sub> emissions. Therefore, when analyzing the calculation result, it must be taken into account that the emissions are not measured and presented without possible NO<sub>x</sub> reduction techniques. NO<sub>x</sub> emissions from combustion and transport constitute the most significant origin of NO<sub>x</sub> emissions in the natural gas lifecycle.

SO<sub>2</sub> emissions originate solely in the natural gas purification process in Russia. SO<sub>2</sub> emissions released into the atmosphere result in the formation of sulphuric acid and sulphuric acid salts in the soil and water bodies, and when inhaled may cause health impacts and damage vegetation. Most of the sulphur dioxide emissions globally originate in industrial operations such as the processing and burning of fossil fuels. Since the 1980s and 1990s, the total sulphur dioxide emissions in Finland and globally have fallen dramatically and the impact of emissions is currently mainly local.

The GHGs calculated were carbon dioxide (CO<sub>2</sub>) and methane (CH<sub>4</sub>). Methane is a powerful greenhouse gas and, according to the latest IPCC (Intergovernmental Panel on Climate Change) AR5 report (IPCC 2014), when released into the atmosphere, has a 28 times global warming potential than the impact of carbon dioxide. This study applied data from reported methane emissions (leaks and methane slip); however, the sources of reported emissions in Russia were not detailed and the exact amount of possible fugitive emissions is most likely unknown. Also, potential methane slip from natural gas use was not included. Most of the methane emissions calculated originated in the natural gas production and transmission phase in Russia.

When the end-use of natural gas is included, the most significant source of GHGs is the product itself. Burning natural gas accounted for 80% of the GHG emissions in the natural gas lifecycle (CO<sub>2</sub> emissions). Second highest release of GHG emissions (19%) was in Production and Transmission phase in Russia. Transmission in Finland accounted for less than 1% of the total greenhouse gas emissions. Methane emissions (equivalent to CO<sub>2</sub>) during production and transmission in Russia and Finland accounted for only approximately 3% of the total greenhouse gas emissions.

The impact of the natural gas lifecycle on climate change is significant when taking into consideration natural gas combustion. Although natural gas combustion causes less carbon dioxide emissions than oil and coal combustion, reducing the GHG emissions along the supply chain is important.

## 4 OTHER ENVIRONMENTAL IMPACTS OF THE NATURAL GAS LIFECYCLE

### 4.1 Assessment methodology

This section assesses other environmental impacts of the natural gas lifecycle, taking into consideration the lifecycle stages: Production and transmission in Russia, Transmission in Finland and Consumption in Finland. Environmental impacts of the lifecycle can be divided into two phases: development (including construction) and operation. Environmental impacts can be either direct or indirect. Decommissioning of the natural gas operations or infrastructure was not assessed in this study.

The table below (Table 6) presents all the potential environmental impacts of natural gas activities.

**Table 6. Environmental impacts of natural gas activities (modified based on IFC 2007).**

Potential environmental impacts	Extraction/ production	Transmission
<b>Development phase</b>	Transport	Transport
	Noise and vibration	Noise and vibration
	Air emissions	Dust
	Wastewater	Habitat alteration
	Waste	Landscape alteration
	Habitat alteration	Waste
	Landscape alteration	Wastewater
<b>Operational phase</b>		Air emissions
	Air emissions	Air emissions
	Wastewater	Hazardous materials
	Hazardous materials	Waste
	Waste	Noise and vibration
	Noise and vibration	

The lifecycle impacts of were assessed in the form of an expert review based on publicly available information and experience of previous natural gas environmental impact assessment projects. In the study, Pöyry’s experts have focused on the most significant impact categories. For example, the impact of transportation and dust during the development of the natural gas infrastructure can be locally significant but short-term and there are limited ways to reduce the impact.

The impact assessment was carried out at a general level based on the natural gas production and transmission activities and data of Gazprom in Russia and Gasum in Finland. Natural gas end users did not participate in this study. The assessment does not address the local environmental impacts for specific regions as would be done in a statutory environmental impact assessment procedure. Both in Finland and the Russian Federation, an environmental impact assessment procedure is mandatory for projects (such as oil and gas production projects) that may impact the environment. Russian



environmental protection law consists of both federal and regional level regulations. The main principle is that the federal regulations are similar but detailed at the regional level according to the circumstances. In this study, the status of environmental protection requirements nationally or regionally was not studied.

This report does not present the environmental impacts in order of importance.

## 4.2 Biodiversity

Natural gas production and transmission have both direct and indirect adverse impacts on biodiversity. The main impact on biodiversity is the destruction, deterioration and fragmentation of habitats which is caused by the removal, erosion or disturbance of vegetation and soil at production sites, access roads and along transmission pipeline routes. These impacts are apparent in the pre-construction and construction phases of production sites and pipelines.

In the pre-construction phase, off-road driving, test drilling, geotechnical and site studies, soil sampling and other related preliminary work destroy and weaken the untouched vegetated soil surface. The construction of gas fields widely changes the landscape and associated habitats within the project area, including all underground and aboveground facilities. Vegetation and part of the soil are removed, and the area becomes devoid of all flora and fauna. This also affects the behavior and distribution of animals as they have to move to other areas for breeding, resting and feeding. The power of regeneration of vegetation is low in the North and especially in the Arctic tundra biome, because of the short growing season and low heat summation. All activities influencing vegetation therefore have more serious impacts compared to southern, temperate regions.

Adverse impacts are also caused by disturbances due to construction and other land use activities. These disturbances, which include noise, dust emissions and human presence, expel animals from the vicinity of the site and disturb plants, and consequently weaken habitats. Other possible adverse impacts on flora and fauna are exposure to waste and contaminants, salination of the soil due to discharged water, collision risk to vehicles and aboveground facilities, mortality due to gas flares, risk of animals getting trapped inside the facilities, tanks or reservoirs, and disturbances to vegetation from off-road traffic.

The impacts of transmission lines to biodiversity through loss, deterioration and fragmentation of habitats is especially apparent in a forested landscape, where transmission pipelines and potential service roads will heavily change the vegetation because trees are felled and vegetation is heavily managed to keep it low. This could create barriers for dispersal and cause the isolation of populations of certain sensitive species, such as the Siberian flying squirrel (*Pteromys volans*). The area required by transmission pipelines is usually narrow, and therefore the impact is likely to be generally low. However, the possibility to create green bridges or placing the pipelines underground at sensitive sites or vast forested areas should be considered in order to minimize the impact.

In certain cases, transmission lines and service roads can impact positively on biodiversity. Along underground transmission pipe routes, vegetation is managed so that open habitats requiring heat and light, as well as their specialized flora and fauna, can emerge. Many such exposed habitats are endangered, especially in the mainly forested boreal region. Transmission lines can also function as pathways that connect populations of species that will normally not disperse in a forested landscape. This allows gene flow, and thereby increases the viability of such potentially isolated populations. Similarly, the routes enable species to increase their distribution by dispersing to new areas. The endangered butterfly false heath fritillary (*Melitaea diamina*) is a good example of a species that benefits from open, un-forested corridors between the meadows it inhabits.

However, using same mechanism as described above, invasive species can potentially use transmission line routes for dispersal also. Invasive species pose a serious threat to native biodiversity, and invasive species such as the raccoon dog (*Nyctereutes procyonoides*) or the large-leafed lupin (*Lupinus polyphyllus*) are known to utilize forestry service roads and powerline openings for dispersal.

Air emissions (from flaring, as fugitive emissions or from natural gas combustion) do not have any obvious effects on biodiversity from a local perspective. However, natural gas production is increasing globally and despite it being the cleanest of all fossil energy sources, air emissions from increasing production will contribute to the amount of greenhouse gases in the atmosphere, and consequently promote climate change.

Over the past few decades, extensive research has identified several effects of climate change on biodiversity. The most significant effect is the rapid deterioration and loss of habitats. Plants and animals have adapted to their environment over a very long time and they cannot adjust to rapid changes in ambient conditions (such as temperature or precipitation). This will lead to decreasing reproductive success and even cause extinctions. Climate change is also promoting range shifts of fauna and flora, and in the northern hemisphere the shift is usually to the north as the climate becomes warmer. This causes range loss especially to species living in the High Arctic because they are adapted to the cool environment and cannot move any further north towards the sea. On the other hand, climate change will upset the balance of nature and species composition, because certain opportunistic and generalist species are able to adjust more rapidly and spread faster than others, and consequently increase in numbers at the cost of more sensitive species. On a large scale, this has effects across the whole food-chain and causes flora and fauna to become increasingly monotonous.

### 4.3 Natural resources

Production of natural gas has an evident impact on natural resources through the depletion of recoverable natural gas reserves. Natural gas is a fossil fuel and a non-renewable natural resource because it was formed from the buried remains of plants and animals that lived millions of years ago. Once the natural gas reserves are consumed, millions of years are needed to create more. Global natural gas reserves have been estimated to total 7.124 trillion cubic feet (TCF) in 2018 (*EIA 2019*). Gazprom holds 16% of the world's natural gas reserves and 69% of Russia's gas reserves (*Gazprom 2019a*). However, new natural gas reserves are found annually in geological explorations in Russia and globally.

### 4.4 Soil and water quality

Other main impacts concerning earthly natural resources are the possible effects on soil or water quality. Natural gas reserve studies and production directly affect the topsoil and at the same time result in the removal excess soil for underground space for natural gas infrastructure instruments. During drilling operations, either in site development or commencing a new gas well, careful planning of site operations is needed in order to prevent hydrocarbon emissions from underground reaching the upper soil. Gazprom has named land protection as one of its environmental priorities because the land is exposed to major impacts during hydrocarbon production and transportation. Gazprom is limiting site development, construction and assemblage operations in order to preserve Siberian permafrost areas. This means that the operations are carried out without disturbing the upper soil, which thaws during summer. (*Gazprom 2019b*)

In normal operation, no oil hydrocarbons are released into the soil or water bodies. In case of an accident, oil compounds can contaminate soil and since they are carcinogenic substances can potentially cause a risk to animals and humans. Depending on soil type,

polluted soil can transmit substances to underground water reserves if such are present. Methane on the other hand, like other petroleum gases, is not an environmentally hazardous chemical. When natural gas is in contact with the soil, it will evaporate quickly into the atmosphere and leave no traces in the ground. Deterioration of soil quality depends on the environmental protection measures of each natural gas development or operational location. Traditional soil remediation measures are excavation and end treatment of polluted soil outside the study area. These methods require the transport of large soil masses over long distances and also funding. Therefore, it is most efficient for the environment and also cost-wise to treat contaminated soil in situ. According to Gazprom, no significant leakages (over 10 tonnes) of oil or oil products have been detected in their operation (Gazprom 2017). Minor environmental incidents like small oil spills are possible but they have to be dealt with according to Russian legislation and treated locally to prevent deterioration of soil or ground water quality. Gazprom has adopted in situ remediation technologies (using hydrocarbon-degrading bacteria). According to Gazprom, a plant-based treatment procedure (phytoremediation) is also widely used.

Soil quality can also deteriorate organically. When removing the topsoil from the production areas and work area for underground gas installations, soil fertility can decline if the topsoil masses are not placed on top of the construction filling masses. In Finland, the current practice is to return the topsoil. Loss of soil fertility could affect, for example, farming and the recovery of vegetation. Soil quality though differs locally depending on soil type and the climate. For example, some areas in Russia can suffer from topsoil dryness and be more susceptible, for example, to erosion.

Another environmental aspect regarding soil quality is that the temperature of the transmitted natural gas is much higher immediately after production and then slowly decreases during transmission. When the pipelines are located within the permafrost area and if the gas is warmer than the surrounding soil, it is important to keep the pipelines insulated. Gazprom has cooled down pipeline sections to prevent permafrost thawing and the unnecessary release of methane. Also, most of the transmission pipelines across the permafrost area are located above ground and pipelines that are produced in Russia are thermally insulated. Today, the permafrost thawing due to climate change is a serious threat to the integrity of the gas infrastructure and again climate change itself. (Gazprom 2019b)

Natural gas production requires also infrastructure for employees. Sanitary facilities at large production sites produce a lot of wastewater that needs to be treated locally and treated water is released into the surface waters. The efficiency of wastewater treatment technologies has been an issue in Russia that Gazprom has invested heavily in over the years by building and maintaining sufficient treatment plants. (Gazprom 2017)

Process wastewaters from natural gas production include those arising in washing machinery or equipment and potentially, if the method is used, fracking fluids. Process waters may include oil components and be environmentally hazardous. These components must therefore be separated from the water and/or collected and stored separately prior to treatment in a hazardous waste treatment plant. It is not allowed to release these types of hazardous substances for municipal waste treatment and the material should be transported to a hazardous waste treatment plant as in Finland. If natural gas (methane) is transmitted to water, it will evaporate from the surface and rise into the atmosphere. Natural gas itself is not hazardous for the soil or water bodies.

## 4.5 Land use and landscape

Natural gas production and transmission restrict land use activities during the development phase and operation. In Finland, Gasum participates in local and regional zoning

procedures, and transmission pipeline operations are managed in cooperation with land-owners.

The development and construction of the gas infrastructure generally limit the possibilities to utilize land. Access to production or operational areas must be restricted for safety reasons, and in Finland, for example, a non-recurrent payment is made as compensation for the nuisance of land expropriation. However, in natural gas production, advanced exploration technologies (e.g. 3D seismic imaging) and drilling technologies (horizontal and slanted wells) reduce the amount of land disturbed. Development of natural gas production and transmission when above ground will in most cases turn a rural area into a built industrial environment. This will affect the landscape and change the natural environment via deforestation and aboveground infrastructure and buildings. In the construction phase, laying a pipeline will require a work area in which trees will need to be felled, and the existing ground vegetation will be destroyed. After commissioning, the worksite area's flora and landscape can gradually be restored.

During operational phase, the restricted land use areas close to transmission trunk pipelines are narrower than in the construction phase. In Finland, natural gas pipelines are located underground but in Russia where aboveground installations exist, land use and other activities surrounding the pipelines are more widely limited. When the pipeline is located underground, some land use activities are allowed (for example, farming). Only storing heavy loads or planting trees, for example, or some other activity that could risk the integrity of the pipeline are strictly forbidden. Even where vegetation is restored, natural gas pipelines are kept safe from potential hazards like tree roots by clearing the vegetation right above the pipeline section. Impacts on landscape are local but permanent, depending on the decommissioning activities. The production or pipeline area will stand out from the otherwise forested environment as a treeless area or corridor. In Finland, also all aboveground equipment is fenced.

## 4.6 Noise and vibration

### *Noise*

In Russia, the production of natural gas imported into Finland causes noise impacts mainly around the gas wells and gas fields (Yamal, Yamburg & Urengoy). In gas fields, the main sources of noise during the production of natural gas would include compressor and pumping stations, production wells (including occasional flaring), and vehicle traffic. Depending on the size of the noise zone around the gas fields, the primary impacts from noise would be localized disturbance to wildlife, recreational pursuits, and residents.

Noise impacts during the transmission of natural gas both in Russia and in Finland mainly comprise compressor station noise, which will consist of noise generated by the compressor and the gas turbine powering it. In Finland, operations causing excess noise are licensed by an environmental authority.

Compressor station noise can be described as a low humming sound in the surroundings. Outdoor noise sources include the gas turbine air intake, exhaust gas outlet and any condenser fans. Results of the Environmental Impact Assessment in Finland (*Gasum 2015*) show that the noise zone of 45 dB(A) from a compressor station will extend to a maximum of around 150 meters from the compressor station. Noise sources from different compressor stations are similar, however, there are no facts about the noise levels of Russian production fields or compressor stations.

Pipeline transmission itself does not cause any noise but in case of a maintenance break or malfunction of gas infrastructure equipment, noise from transmission pipeline operation can occur. Transmission operation noise sources can be classified as either continuous or intermittent. During operation, noise will be generated by 1) the pipeline (from

blowdowns) and 2) maintenance work, such as the use of vehicles. Based on data from similar reports, the noise impact from these actions will, however, be insignificant. For maintenance purposes, pipeline blowdowns (releases of natural gas) may be carried out, resulting in a strong and noticeable whistle-like sound. Such blowdowns last only a few minutes and are very seldom (for example, in Finland only a few times a year in total). (*Gasum 2015*)

### **Vibration**

When in operation a gas turbine causes vibration inside the turbine hall. Also operations resulting from the compressor or pumping stations and traffic around gas wells and gas fields can cause vibration. Other than this, the gas infrastructure does not in normal circumstances cause any noticeable or significant vibration during operation, and the most important issue regarding vibration is the potential vibration from other sources caused to natural gas pipelines.

Vibration can be caused also during gas infrastructure construction. The drilling of boreholes can cause vibration near the drilling area during the study or production phase of natural gas fields in Russia. Also, construction work when building onshore pipeline structures can cause vibration, especially the blasting of a pipeline corridor in the bedrock.

Vibration impacts in general are not significant and during construction work are short-term in nature. Vibrations caused by blasts will usually last only a few seconds at a time. Vibrations are usually detectable up to 500 meters from the excavation site when blasting or drilling is carried out in a controlled manner. Vibrations may, however, also extend further depending on issues such as soil geology. Vibration can cause momentary annoyance to people and animals. In some cases, intensive vibration may damage structures and sensitive instruments.

## **4.7 Waste management**

Natural gas production (gas well operation and operations at the gas fields) generates mostly common residential wastes from daily staff routines. In addition to this, boring gas wells generate drilling waste (drill mud and cuttings) and all production operations generate industrial wastes such as lubricating oils, hydraulic fluids, coolants, solvents and cleaning agents. Hazardous wastes are typically placed in containers, characterized, labeled and possibly stored before being transported by a licensed hauler to an appropriate permitted off-site disposal facility.

Natural gas transmission operations do not generate waste other than oil sludge that consists of sand or clay and hydrocarbons. Oil sludge is a result of gas refining and pipeline cleaning. This solid waste can be transmitted long distances inside the pipeline network. The oil sludge transmitted to Finland is caught in a trap, collected annually and sent to treatment as hazardous waste.

Waste management in Russia is under development and therefore Gazprom is working under a specific waste management master plan. The plan involves Gazprom facilities in all regions across Russia. This master plan was not available online.

Until recently, landfill has been the normal practice of processing waste in Russia. A particular challenge in operating in remote areas is that there is most likely no waste management infrastructure in place. Gazprom has been actively taking part in training their employees in waste management and making an effort in cleaning areas where wastes have been dumped or discarded. Gazprom and its employees initiate and participate in environmental cleaning operations, for example at Tambey trading station in the Yamal Peninsula many hectares of the coastline were cleared of production waste (including scrap metal and debris) dumped there since Soviet Union times. (*Gazprom 2017*)

Despite most of the waste generated being common household waste, all waste disposal in industrial operations is always a high environmental risk. Gazprom has committed to decrease the amount of accumulated waste. (*Gazprom 2017*)

#### 4.8 Potential impacts of accidents or operational malfunctions

Siberian natural gas consists of approximately 98% methane (CH<sub>4</sub>). Methane (CAS number: 74-82-8) is classified as an extremely flammable gas. Its range of ignition in air is 5-15%. For safety reasons, methane is stored in closed systems in well-ventilated places. Petroleum gases, including methane, are not classified as environmentally hazardous. Safety precaution methods for methane include keeping the chemical away from sources of ignition and excess heat. Methane is lighter than air. In case of a leakage, the gas will evaporate quickly and rise into the atmosphere. (*Finnish Gas Association 2014 and ECHA 2019*)

Oil and gas production and dealing with hydrocarbons require considerable attention to health and safety issues. Gazprom and Gasum operate according to certified occupational health and safety management systems, and safety is at the core of their operation. Potential impacts of natural gas operations most commonly include an accidental gas pipeline rupture caused by outside intrusion and only secondary some type of accidental malfunction of operational equipment. Natural gas accidents or explosions are rare, but when they do occur, they can cause death or injury to workers and nearby civilians. Natural gas leaks do not cause environmental pollution but increase the amount of methane in the atmosphere. Contamination of soil or water bodies can occur when natural gas is associated with oil production. During a leak, natural gas will rise quickly into the atmosphere and only larger amounts in closed spaces and in contact with air can cause an explosion or fire. In addition to threatening people, accidents could threaten infrastructures as well as flora and fauna.

In normal operations, near-miss situations or accident rates can be referred to any industrial operation. Seven cases of accidents that had an environmental consequence were reported at Gazprom in 2018. These cases were a destruction caused by micro crack formation in the pipeline, corrosion, emission and therefore destruction of a pipeline, technical defect as a result of mechanical impact on a pipe surface and mechanical damage due to heavy machinery. (*Gazprom 2019a*)

## 5 UNCERTAINTIES

Impact assessments, as such, always include some assumptions and generalizations. This study was carried out as a desktop study based on expert experience, information received from Gasum and publicly available sources. The study does not address the specific circumstances along the supply chain of natural gas and therefore the impacts are discussed at a general level.

Depending on the availability of data, some uncertainties may occur. Raw data regarding Russian operations was not available and therefore Gazprom's Environmental Report 2018 and their official website were used. Although Gazprom's GHG emission reporting is verified, some inaccuracies might exist particularly regarding fugitive methane emissions.

Oil and gas production has been identified as a major contributor to methane emissions into the atmosphere but to measure or verify the magnitude of these emissions is challenging. Therefore, the reported amounts of methane and CO<sub>2</sub> equivalent emissions from Gazprom and the environmental reports have been used although they do not detail the emission sources. However, the data from Gasum was accurate and more detailed.

Despite some uncertainties, the assessment gives a reliable overview of the environmental impacts of the natural gas lifecycle.

## 6 COMPARISON TO SIMILAR STUDIES

Before this study, similar studies in Finland have been carried out in 2011, 2014 and 2015. These studies have included an evaluation of the environmental impacts of the natural gas lifecycle, mainly focusing on air emissions from different stages of the lifecycle. All of the studies rely on information produced in other sources.

This study and the air emissions calculation followed the basic principles of the last two similar studies. In Aalto University's publication (Ruonakoski T. 2011), the calculation included CO<sub>2</sub> and CH<sub>4</sub> (production and handling of natural gas), N<sub>2</sub>O (transmission) and CO<sub>2</sub> (use) emissions. Therefore, this study includes a wider range of emission parameters. There were some differences between this study and the study carried out by Neste Jacobs Oy in 2015 which included separately the emissions caused by natural gas use during transmission in Russia. This might explain the differences in the reporting of GHG's by Gazprom at the time. In this study, the total amount of greenhouse gas emissions includes also the emission sources from the natural gas transmission network (the UGSS). Also, the study in 2015 included all hydrocarbon releases into the air and these were calculated according to methane's global warming potential.

Despite the possible inaccuracies in comparison, the total amount of GHGs as CO<sub>2</sub> equivalent evaluated were (including the use of natural gas) 64.16 tonnes per TJ in 2011, 62.97 tonnes per TJ in 2014 and 68.76 tonnes per TJ in this study (data from 2018). Because it was not possible to study the previous calculation and the reporting had its limitations, the basis of the calculation might have some differences which are reflected in the final results. As the data sources from Finland are well known, the results from Finnish operations are similar between the studies. The total amount of GHGs in Finland has decreased. In 2014, the reported GHG emissions in Finland from energy consumption and other emissions in total was 18,828 tCO<sub>2e</sub> (Neste Jacobs Oy 2015). This study shows that Gasum's operations in Finland emitted 18,691 tCO<sub>2e</sub>.

The GHG emissions for the Russian natural gas supply chain to Germany were studied in a study by Wuppertal Institute (Wuppertal Institute 2005) and used as a source in Aalto University's study in 2011. Wuppertal Institute's study included measured information about methane releases from the Russian natural gas infrastructure. A comparison of different GHG emission calculation results in the study shows that total calculated GHG emissions for the natural gas production chain varied from above 60 tonnes per TJ to over 80 tonnes per TJ. (Wuppertal Institute 2005)

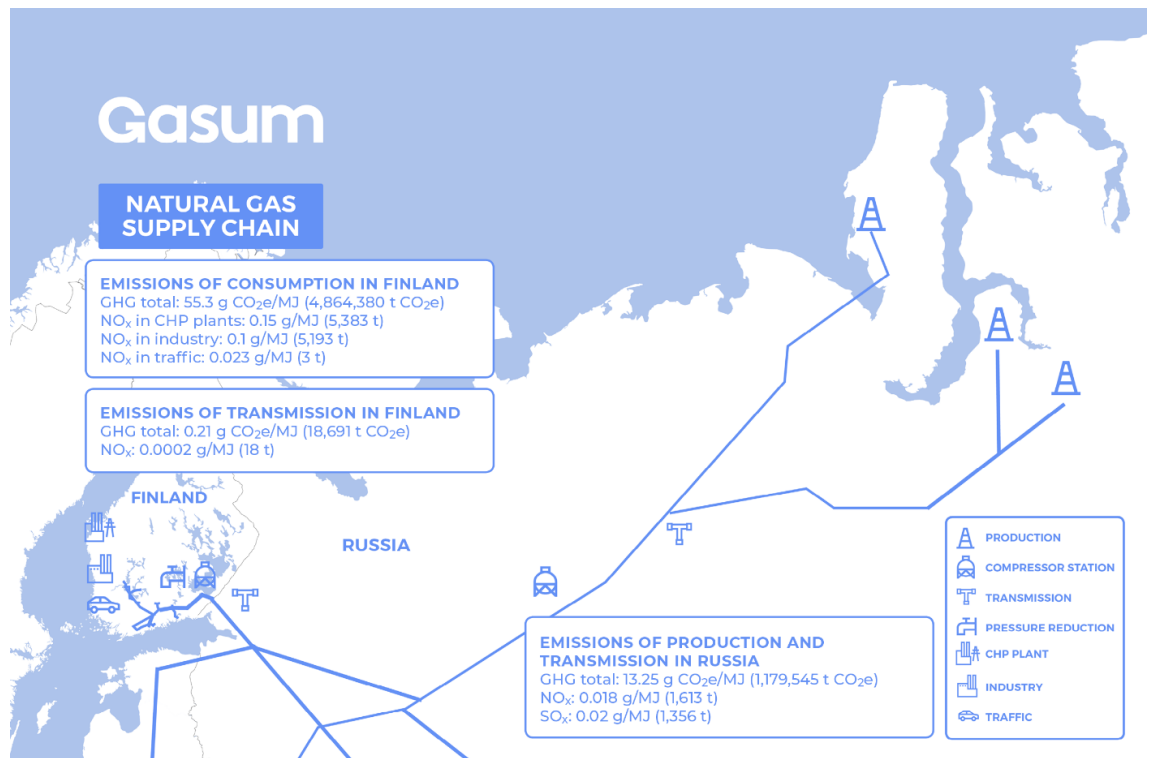
VTT Technical Research Centre of Finland Ltd has studied greenhouse gas emissions for the supply chain of different heating fuels (VTT 2018). In this study, GHGs are presented from production to delivery (so called "cradle to gate") and the combustion of fuels was not included. This study applied data from several sources. For the Russian natural gas supply chain, the most relevant sources were Joint Research Centre's (JRC) EUCAR-CONCAWE collaboration from 2014 and a study conducted for DG Ener (Directorate-General for Energy, European Commission, 2015). JRC's 2014 studies included both natural gas vehicle use and electricity and heat production. GHG emissions from the JRC studies for the natural gas lifecycle were approximately 12 tonnes per TJ and over 15 tonnes per TJ (VTT 2018). Compared to this, the result of this study is in the same range (total of 13.46 tonnes per TJ from production and transmission). On the other hand, the study conducted for DG Ener included the actual GHG emissions for different fuels from several countries and production methods and resulted in GHG emissions of almost 30 tonnes per TJ. (VTT 2018)



## 7 CONCLUSIONS

The environmental impacts of the natural gas lifecycle from Russia to Finland were studied based on publicly available information and GHG emissions from the product lifecycle were determined based on reported data from 2018. Based on the calculation, most GHG emissions are caused by natural gas combustion itself (natural gas consumption, 80%). The emissions from the consumption phase are from the use of natural gas in CHP plants, industry or transport. Operations in Russia (production and transmission) emitted 19% of the total GHGs. Natural gas transmission in Finland caused just less than 1% of the total greenhouse gas emissions.

Most of the GHG emissions in the natural gas lifecycle consisted of carbon dioxide emissions, and methane emissions accounted for only 3% of the total emissions. Based on this study, the total amount of methane loss in the supply chain (consumption phase not included) was 0.34% of the natural gas delivered. This is significantly lower than the methane loss that, according to research, maintains the benefits of natural gas compared to coal when burned at CHP plants. Scientific and industry literature presents several methane loss rate percentages and these range from 1.7 to 5.5%. (IEA 2017, Alvarez R. A. et al. 2012 and IPCC 2014, PSE Health 2015 and GIE and Marcogaz 2019)



**Figure 8. Total air emissions of the natural gas supply chain. The figures are based on reported data from 2018.**

Proper maintenance and operation of natural gas infrastructure is a key factor in reducing GHG emissions. Although the natural gas network is a closed system, the amount of fugitive emissions can increase due to equipment aging and material corrosion. Fugitive emissions from natural gas equipment can be reduced and prevented by monitoring the pipeline infrastructure and following maintenance operations accordingly. In Finland, reducing methane emissions is part of normal transmission network surveillance and maintenance which are supervised by a national authority.

Gazprom and Gasum have both reported their methane release into air annually and are committed to reducing these emissions. Gasum has been reducing the amount of methane leakages by implementing a large-scale renovation program in its natural gas

network. Also, blowdowns across the network have been planned carefully in order to prevent unnecessary release of pure methane into the atmosphere. Where a section of pipeline needs to be emptied, it is firstly sent towards a customer location so that the natural gas can be used instead of releasing it into air. Also flaring is the preferred practice compared to venting but reducing any unnecessary air emissions requires also efficient use of the natural gas produced or transported. Gasum has carried out a systematic renewal of old valves along the transmission network. Gasum has a maintenance program that has been implemented systematically in its transmission network and which can be followed on a daily basis at a location and equipment level. This should also prevent unnecessary emissions into the environment. Also, Gazprom aims to cut down in particular on its pollutant and greenhouse gas emissions.

Since the majority of GHGs from the natural gas lifecycle originate in the use of natural gas, it is important to further develop the future replacement of fossil methane with bio-methane and techniques such as CCS (Carbon Capture and Storage).

Other significant environmental aspects in the natural gas supply chain are the alteration of land and vegetation, utilization of natural resources in general and waste and wastewater management procedures in Russia. However, these are typical impacts of industrial activities or construction. By using the best available technology and implementing statutory environmental impact assessment procedures, the impacts can be decreased or minimized.

Compared to other fossil fuels, the combustion of natural gas causes the least amount of CO<sub>2</sub> emissions and its climate impact is therefore smaller. In Finland, Gasum has measured fugitive methane release from valves and the total amount including possible releases from the pressure reduction stations are evaluated accordingly. Also, methane releases due to maintenance work are calculated. In general, in order to get more thorough view, fugitive methane emissions along the entire supply chain should be studied further. Also, it might be interesting to assess the complete greenhouse gas inventory of transmission via gas grid compared to off grid supply methods.

## 8

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