"LIFE CYCLE ASSESSMENT OF THE EUROPEAN NATURAL GAS CHAIN
– A EUROGAS – MARCOGAZ STUDY"

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1. Introduction

1.1. Life cycle thinking – an essential approach for the gas industry in Europe for a fair comparison between energy carriers

Initially, Life Cycle Assessment (LCA) was developed by and for the industry in order to make strategic decisions concerning the environment. The first LCA was conducted by Coca Cola in 1969 and, contrary to all expectations, it revealed the plastic bottle as the best choice from an environmental point of view. Later in the 90's LCA was more broadly used to manage the global scope of environmental problems.

According to the ISO 14040 and 14044 standards [1] Life Cycle Assessment is a global environmental assessment method to evaluate the environmental burdens (greenhouse effect, acidification, resource depletion, etc.) associated with a product or activity over its complete life cycle. This approach is also called a "cradle to grave" evaluation.

Considering the whole life cycle helps to ensure that no environmental burden is shifted from one to another life stage or among different impacts, as it consider parallel effects on various environmental impacts: it is therefore a primordial approach to improve entire systems, and not solely single parts of the systems considered, by avoiding decisions that fix one environmental problem but cause another unexpected or costly one (like mitigating air pollution while increasing water pollution).

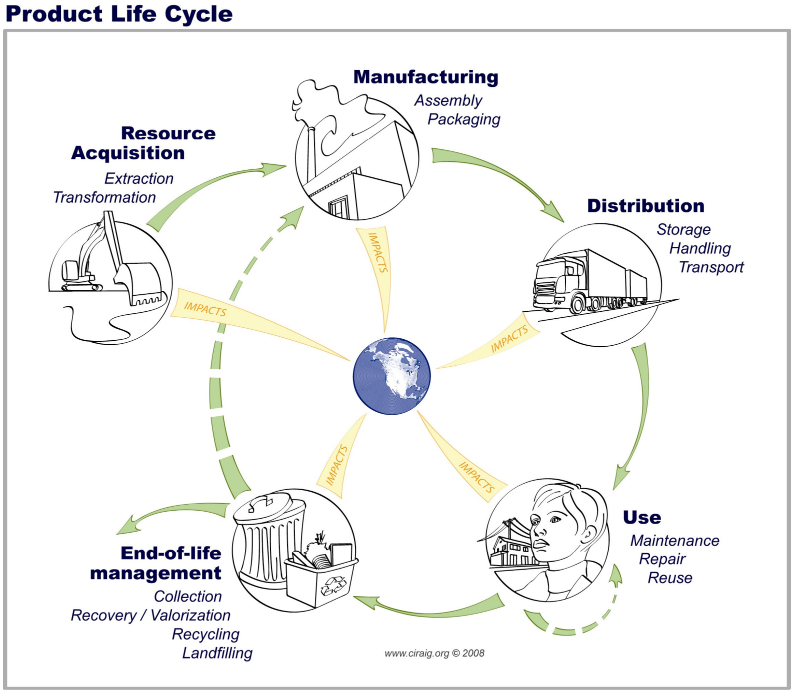

Figure 1: Product Life Cycle

The life-cycle thinking is a particularly important approach for the European natural gas industry:

- ✓ **Looking at the whole life cycle allows prioritizing our actions:** the environmental balance of the energy delivered to the consumer exceeds by far the borders of European gas companies' activities. Europe being a net importer of natural gas, nearly 65% of the greenhouse gases (GHG) emissions due to the delivery of low-pressure natural gas in Europe take place outside the European borders. The natural gas combustion being accountable for about 85% of the greenhouse gases emissions of the whole chain, natural gas activities of European gas companies in Europe do contribute to less than 6% of the greenhouse gas emissions. Therefore, taking into account the whole life cycle of our product, and especially its utilization, is the only way to assess the real impact of our efforts and to prioritize our actions.
- ✓ **Looking at all environmental impacts highlights the advantages of natural gas and support the environmental balance of our energy:** looking only at the carbon content as it often happens nowadays - by using the Carbon Footprint for example - is not enough. When exclusively carbon footprint data are used to support procurement decisions or to improve goods and services, other important environmental impacts are neglected. This single-impact approach highlights the performance of natural gas in comparison with other fossil fuels. However, when compared to others energy sources like renewable energy resources or even nuclear energy, the balance can be in disadvantage of natural gas. Looking at all impacts is much more fair to position natural gas and highlights some less known weak points of other energy carriers: particulate matters emissions for wood, radioactive waste for nuclear energy, consumption of limited mineral resources for photovoltaic systems, etc.

1.2. The Eurogas-Marcogaz working group on LCA: an opportunity to support natural gas in a context of development of life-cycle oriented regulations

LCA is a powerful tool that can potentially assist regulators to formulate environmental legislation, help manufacturers to analyze their processes and to improve their products, and eventually enable consumers to make more accurate choices when they buy products.

Recently, life cycle oriented European strategies and directives emerged, among them:

- ✓ The Integrated Product Policy (IPP) - 2003: IPP seeks to minimize the environmental impacts of a product by looking at all phases of its life cycle and taking action where it is most effective. IPP is a toolbox of environmentally focused product policies (EPP) intended to help creating green markets by promoting a combination of mandatory and voluntary measures
- ✓ The Directive on Ecodesign requirements for Energy-using Products (EuP) – 2003: EuP intends to regulate products, and the method of designing products, that consume energy (whether electricity, fossil fuels, or renewable energy resources) to fulfill the purpose for which they were designed. The primary aim is to encourage producers designing their product bearing in mind the environmental impacts potentially occurring at each stage of the product entire lifecycle, to give freedom of informed choice to the customer, and to create a level playing field within the EU for such products.

To support this policy with reference data and recommended methods on Life Cycle Assessment, the European Commission has therefore launched in 2005 the European Platform on LCA. The purpose of this platform is to improve credibility, acceptance and practice of Life Cycle Assessment (LCA) in business and public authorities, by providing reference data coming from the industry. The main deliverable of the project is the "European Reference Life Cycle Data System" (ELCD), a Life Cycle Inventory data from European business associations for key materials, energy carriers, transport, and waste management.

Natural gas data based on standard LCA data coming from existing databases are already online, based on standard LCA data coming from existing databases. Numerous databases give indeed life cycle data on the gas industry: however, none is made or even validated by gas companies. There was therefore a real need for data validated by the industry.

The gas industry anticipated these evolutions and took already actions since many years:

- → The IGU published “Natural gas - Toward a global life cycle assessment” [35], the result of a group of IGU’s studies during the Dutch Triennium 2003-2006. The aim was to perform a life cycle assessment of the natural gas chain and collect data from industries on consumptions and emissions along the life cycle of natural gas. This report describes the initiation of the life-cycle inventory. This study gave life cycle inventory data for each step of the gas chain. However, these data were not aggregated on the whole gas chain, from production fields to the consumer.
- → Since 1993, the Eurogas-Marcogaz Joint Group Environment, Health and Safety has collected technical and environmental data to monitor and improve environmental performances of the European gas industry (see § 2.5). Anticipating the future consequences of the European IPP, it was therefore decided to use these data to assess the impacts of the whole life cycle of natural gas in Europe: Marcogaz and Eurogas launched in 2004 a working group which aims to provide reliable LCA data for Europe coming from the gas industry itself. GDF SUEZ has been working on LCA since the early 1990’s and developed a particular expertise on Life Cycle Assessment through the study of many energy systems, among which the natural gas chain. As a consequence, GDF SUEZ has led the dedicated Eurogas-Marcogaz WG on LCA, with the participation of industrials (Gasunie, Snam Rete Gas, Eon-Ruhrgas, Fluxys and Distrigas) and associations (DVGW, Synergrid). The objectives of this working group are twofold:
  - ➢ Improving knowledge of natural gas environmental performances and assigning priorities. As the working group is representative of the European gas industry, its life cycle approach and methodology could also be beneficial to gas companies in Europe.
  - ➢ Supplying the European Policies with high quality LCA data, validated by the gas industry itself. This working group therefore meets the objectives of the previously named “European Platform on Life Cycle Assessment”, the project of the European Commission. Marcogaz, as other European business associations, members of the group, committed to provide life cycle inventory (LCI) data sets of our key product and/or processes, as far as available, for publication in the ELCD core database. This common work is still in progress.

2. METHOD

2.1. Generalities on LCA methodology

According to the ISO 14040 [1] and 14044 [2] standards, a Life Cycle Assessment is carried out in four distinct phases.

a) Goal and scope

In the first phase, the LCA practitioner formulates and specifies the goal and scope of the study in connection with the intended application. The object of the study is described in terms of a so-called functional unit. Apart from describing the functional unit, the goal and scope should address the overall approach used to establish the system boundaries. The system boundary determines which unit processes are included in the LCA and must reflect the goal of the study. Finally the goal and scope phase includes a description of the method applied for assessing potential environmental impacts and determining which impact categories that are included. This step is crucial: an LCA is goal dependent. Its results will be dependent from the hypotheses taken in this first step.

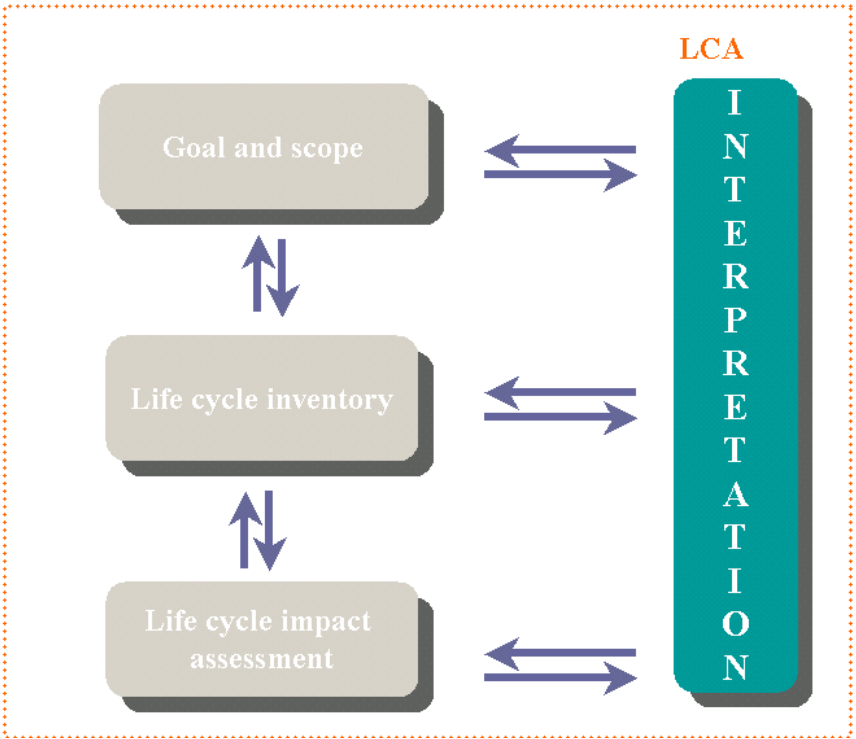

Figure 2: LCA methodology

b) Life cycle inventory (LCI)

This second phase 'Inventory' involves data collection and modelling of the product system, as well as description and verification of data. This encompasses all data related to the environment (e.g., CO_2) and the techniques (e.g., intermediate chemicals) and quantities for all the relevant unit processes that compose the product system within the study boundaries. Examples of input and output quantities include inputs of materials, energy, chemicals, etc. - and outputs in the air emissions, water emissions or solid waste. Other types of exchanges or interventions such as radiation or land use can also be included. Usually Life Cycle Assessment inventories and modelling are carried out using dedicated software packages. Depending on the software package used it is possible to model life cycle costing and life cycle social impacts in parallel with an environmental life cycle.

The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables and some interpretations can already be made at this stage. The results of the inventory is an LCI which provides information about the inputs and outputs in the form of elementary flows to and from the environment from all the unit processes involved in the study.

c) Life cycle impact assessment

The third phase 'Life Cycle Impact Assessment' aims at evaluating the contribution to impact categories such as global warming, acidification, etc. The first step is termed characterization. At this stage, impact potentials are calculated based on the LCI results. The next steps are normalization and weighting, but these are both voluntary according to the ISO standard. Normalization provides a basis for comparing different types of environmental impact categories (all impacts get the same unit). Weighting implies assigning a weighting factor to each impact category depending on the relative importance.

d) Interpretation

The final stage 'interpretation' is the most important one. An analysis of the major contributions, sensitivity and uncertainty analyses lead to the conclusion whether the ambitions from the goal and scope can be met. More importantly: what can be learned from the LCA? All conclusions are drafted during this phase. Sometimes an independent critical review is necessary, especially when comparisons that are used in the public domain are made.

2.2. Goal and scope

a) Functional units and system boundaries

The goal of this study is to establish the life cycle assessment of three different natural gas utilisations, addressing electricity production, heat production and combined heat and power generation in an average place in Europe in 2004. The geographical borders of the study are therefore limited to the 25 members of the European Union.

This LCA study focuses on selected best available conversion technologies for heat and electricity production (current state-of-the-art technology in 2004).

The following energy conversions have been studied:

- → Electricity generation from a natural gas combined cycle (NGCC) power plant,
- → Heat production using a condensing modulating boiler
- → Combined heat and power generation from small natural gas combined heat and power units

The assessment addresses large-scale power plants for electricity production only, small-scale units for combined heat and power production (CHP plants), and boilers (for households and industry) for heat production.

The final functional unit is: *"to deliver 1 kWh of useful heat/electricity to consumer in Europe in 2004"*.

Best Available Technologies (BAT)

Electricity production:
- ✓ Combined Cycle (CC) plant 800 MW_e base-load

Heat production:
- ✓ Boiler 10 kW_{th} (condensing & modulating)
- ✓ Boiler >100 kW_{th} (condensing & modulating)

Combined Heat & Power (CHP) production:
- ✓ Gas motor CHP 30 kW_e (condensing)
- ✓ Stirling motor micro CHP 1 kW_e

The following figure illustrates the borders of the considered systems:

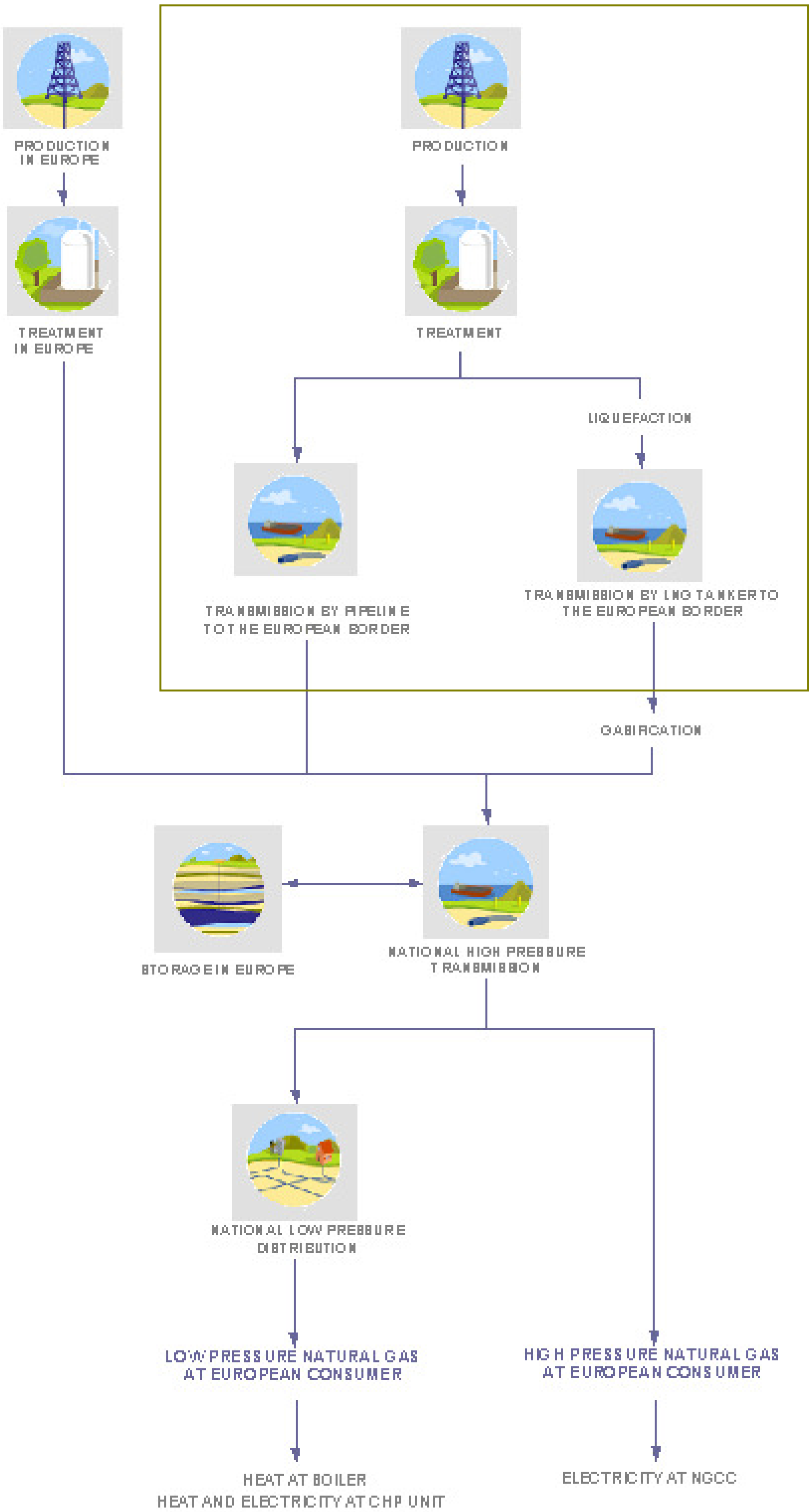

Figure 3: System boundaries

b) Focussing on key flows and impacts

The inventory result of an LCA usually contains hundreds of different emissions and resource extraction parameters. In this study, our aim was to focus on the main environmental impacts of our systems and flows on which we can provide a real added value regarding the quality of the data. It was therefore decided to focus on the principal emissions and consumptions of natural gas activity that are:

- ✓ Atmospheric emissions: CO_2, CH_4, NO_x, SO_2, CO, particulates, NMVOC (Non Methane Volatile Organic Compounds)
- ✓ Energetic consumptions: natural gas, oil, coal, uranium, hydropower

In Life Cycle Impact Assessment (LCIA), inventories of emissions and resources consumed are assessed in terms of impacts. Numerous LCIA methodologies have been developed by universities or research centres, sometimes based on different principles, that lead therefore to different conclusions. This is especially the case for the assessment of impact on human toxicity and ecotoxicity effects.

The Marcogaz proposal therefore restrained the number of impacts followed to three main impacts for which a consensus has been found:

→ **Global Warming:** a greenhouse gas indicator, the global warming potential (GWP), is used to compare the ability of different greenhouse gases to trap heat in the atmosphere. It is derived from two basic properties of each gas: the first is its radiative efficiency (heat-absorbing ability); the second is its decay rate (the amount removed from the atmosphere over a given number of years). These properties are compared to those of carbon dioxide. The GWP provides a tool for converting emissions of various gases into a common measure, which allows climate analysts to aggregate the radiative impacts of various greenhouse gases into a uniform measure denominated in carbon or carbon dioxide equivalents. IPCC climate change factors considered in this report are the latest published by the IPCC and have a timeframe of 100 years :

Compound	Global warming potential (kg eq. CO_2/kg)
CO_2	1
CH_4	25
N_2O	298

Table 1: Global warming characterisation factors - timeframe of 100 years (IPCC 2007)

→ **Acidification**: natural rain is slightly acidic due to the presence of various acids in the air that are washed out by rain. However, a number of man-made emissions are either acidic or converted into acid by chemical processes in the air. Examples of such emissions are sulphur dioxide (which becomes sulphuric acid) and nitrogen oxides (which become nitric acid). As a result, the acidity of rain can be substantially increased by anthropogenic emissions and in a number of areas (such as large areas of Sweden), the soil and water have a limited capacity to neutralize the resulting acids. If water becomes too acidic, an increasing number of aquatic species are harmed and the ability of plants to grow and thrive is harmed if the soil becomes too acidic. An acidification indicator is derived by assuming that 100% of an emission is converted into acid and falls into a sensitive area. The acidity of each emission is converted into equivalent amounts of sulphur dioxide. All emissions are then added into an overall acidification indicator score that represents the total emission of substances that may form acids. The impact assessment method used to characterise the acidification activity is the following: CML 1992 – acidification potential.

Compound	Acidification potential (kg eq. SO_2/kg)
SO_2	1
NO_x	0,7

Table 2: Acidification characterisation factors (CML- 1992)

→ **Cumulative Energy Demand**: the Earth's natural resources are vital for the survival and development of the human population. Some of these resources, such as fossil fuels are limited. Others fuels, such as biomass, wood, water through hydraulic electricity, wind or solar energy are renewable - although we generally rely on the Earth's natural systems to regrow, renew, and purify them for us. Although many effects of over-exploitation are experienced locally, the growing interdependence of nations and international trade in natural resources make their management a global issue. Natural gas is the main contributor to energy consumption for the gas industry. However some other fuels like diesel, heavy fuel oil or electricity may be used at several stages of the life cycle; that is the reason why we will also follow oil, coal and uranium. The energy depletion is expressed in *kJ surplus*, which means the additional energy requirement to compensate lower future ore grade. The impact assessment method used to characterize the non renewable energy consumption is the Cumulative Energy Demand (CED) non renewable.

To increase the reliability of the study, sensitivity analyses have been performed to assess the impact of theses methodological choices by calculating the results with others impact assessment methods.

c) Allocation modes

According to the ISO standard, allocation is defined as the partitioning of the input or output flows of a process or a product system between the product system under study, and one or more other product systems [1].
Many steps of the gas chain produce more than one product: production of gas in associated fields, liquefaction, sweetening, or utilization in CHP:

→ Production: in some case, oil and gas are produced from the same field and with the same equipments. Data are then available for both oil and gas

→ Liquefaction: during the step of liquefaction, some co-products may also be generated, such as sulphur, LPG, gasoline, sometimes helium. These products have a commercial value and a part of the impact of the liquefaction process can be allocated to them.

In general, the ISO standard suggests allocating the environmental load based on a physical causality, such as mass or energy content of the outputs.

Therefore, an energy allocation will be applied to the production and liquefaction steps.

Regarding CHP, two standard allocation schemes are used for the calculation of the cumulative environmental burdens for the whole natural gas chain - energy and exergy:

✓ In case of energy allocation, the same weights are assigned to the products heat and electricity, i.e. the useful energy has the same value regardless of its nature. The allocation factors are in this case directly proportional to their net efficiencies.

✓ In case of exergy allocation, the weight of useful heat depends on its temperature: the higher the temperature, the higher its weight. However, due to thermodynamic reasons, the weight of the useful heat will always be lower than 1, which is the weight of electricity per definition.

Why do we need allocation?

Many processes usually perform more than one function or output. The environmental load of that process needs to be allocated over the different functions and outputs. There are different ways to make such an allocation. CHP units produce heat and electricity at the same time. Therefore, the total associated environmental burdens have to be allocated with so-called allocation factors to these two products.

How to allocate the environmental burdens?

There are various ways of determining the allocation factors: they can be based on the energy content of the products, their exergy content, their costs or prices, etc. The burdens can also be exclusively allocated to the main product, i.e. the by-products are declared as burden-free.
Products credited with more value (in economic or energetic terms) have higher allocation factors than their co-products.

What are the effects on LCA results?

The higher the allocation factor for one product in proportion to the factor(s) for the other product(s), the more environmental burdens it has to carry.

It has been shown that the allocation method chosen has a strong influence on the cumulative LCA results for CHP plants per unit of heat and electricity. The allocation based on exergy is not always adequate to characterize the electricity supplied by CHPs, in particular in the case of the Stirling Micro CHPs because of their relatively small electricity-to-heat ratio. Indeed, when choosing an allocation mode, the LCA practitioner has to focus on the primary function of the system: in the case of micro-CHP, this primary function is to provide heat for individual households. A secondary function is to provide additionally some electricity to reduce the net electricity consumption of the house. Therefore, it would not be relevant to apply exergy allocation to such systems. Results for CHP will therefore be presented considering the energy allocation.

d) Exclusions

This LCA does not integrate data from the exploration stage. Indeed, exploration is made by petroleum companies for both oil and gas. A published study showed that the energy consumed for exploration of gas fields do only reach 0,0002% of the energy content of the produced natural gas [5]. Moreover it is very hard to allocate the impact of an exploration campaign to oil or to gas, when nothing is found.

This LCA does not include emissions related to buildings and vehicles and emissions related to the building and decommissioning of gas equipments.

This LCA does not integrate infrastructures. The decision can be justified by the relatively low contribution of infrastructure to the cumulative LCA results for the analysed impact categories. Literature sources [3] show that less than 0,5% of greenhouse gas emissions from natural gas supply were due do the infrastructure. These contributions are further reduced when conversion of natural gas to heat and electricity is analysed. However, contribution from infrastructure to acidification for electricity and heat can be more significant.

To increase the reliability of the study, sensitivity analyses have been performed to assess the importance of the infrastructures on the final results, based on standard data coming from LCA databases.

2.3. Data collection

a) Data collection methodology

The present LCA study includes all relevant phases of the natural gas chain, which means 9 steps, from production to low pressure distribution.

Sources of data studied give figures of different types:

- → Some gas companies publish their consumptions for fuel, flares and even fugitive emissions;
- → Some publish their emissions in grams (CO_2, methane, etc);
- → Some publish the results of their impact assessment in grams equivalent CO_2;
- → Others publish both consumptions and emissions.

In this study it is chosen to focus on consumption figures whenever possible in order to avoid losses of information. Emissions figures are indeed often aggregated figures where it is difficult to figure out whether these emissions comprise indirect emissions from electricity production and in which proportion they come from gas or other consumed fuels such as diesel or heavy fuel oil for example. There is a great risk to double counting or mistakes. Moreover, emissions figures are often incomplete: CO_2 is always followed, but it is not the case for other flows like particles or carbon monoxide.

Preference is therefore given to consumption data, which are called primary data. Once these consumption data have been found, consequential emissions are calculated on the basis of emission factors adapted on gas composition and type of consumption (fugitive emissions, combustion in gas turbine, combustion in gas motor, etc.). As a result, emissions for gas venting or gas combustion are different from one country to another because of the differences of gas composition.

For each of these steps, the same methodology of data collection has therefore been used and the following rates have been collected or estimated:

- → Fuel gas in %: percentage of natural gas used for combustion in gas turbines, gas engines of boilers
- → Flare gas in %: percentage of natural gas flared for safety reasons
- → Vented gas in %: percentage of gas vented from incidents or safety measures

→ Diesel and heavy fuel oil consumption in energy percentage (%): energy percentage of diesel and HFO burned in boilers or emergency generators

→ Electricity consumption in energy percentage (%): energy percentage of network electricity used in electric engines for compression or auxiliaries

→ Material consumption in kg/Nm^3 of gas: other consumptions like chemicals or materials will be taken into account

For each step, the calculation methodology was the following:

→ Emissions were deduced from the energy consumptions by applying emission factors. This presents a double interest: it avoids double counting and allows differentiating emission sources.
→ Emission factors were taken from on-site data when it was available, or estimated from the natural gas composition.
→ The vented gas rates have been deduced from the methane emissions when there was no direct mention of the volume of vented gas.

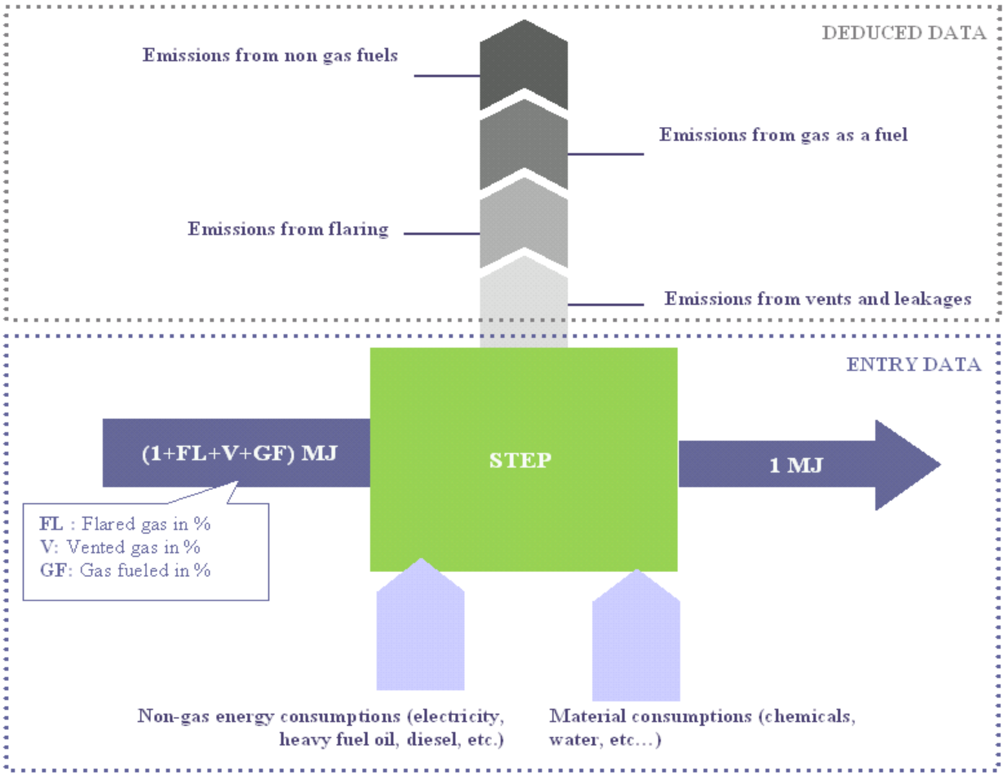

Figure 4: Modelling the steps of the gas chain

b) Data sources

Because a major part of the gas chain occurs outside of the scope of European gas companies, a great work of collecting data from other gas companies had to be done for the part of the gas chain occurring outside Europe. Eurogas-Marcogaz relied on official data from other gas companies (sustainable development report of gas companies, etc.) but also on LCA databases like the ecoinvent database, when no specific data from the gas industry was available.

For the European part of the gas chain, the big European producers – Statoil, NAM, BG, Eni, etc. - publish rather detailed data on their emissions and consumptions. Moreover, the Eurogas-Marcogaz Joint Group Environment, Health and Safety has collected technical and environmental data to monitor and to improve environmental performances of the European Gas Industry. For the collection of the data a questionnaire was sent to several European gas companies on a confidential base. Most of these figures date from 2004, the beginning of data collection. The received data was collected separately for the following steps:
→ Natural gas transmission in Europe
→ Natural gas distribution in Europe

→ Gas storage in Europe
→ Gasification in Europe

For each category, following data are available:
→ Volume of gas per step and company
→ Energy consumption (gas and electricity)
→ Direct NO_x emissions
→ Direct CH_4 emissions

For other countries – Algeria for example -, complete data from gas companies are more difficult to find; therefore, data were taken from well-known LCA databases [5] or adapted from other countries to their national context.

The ecoinvent database: a European reference

The ecoinvent database contains data for various economic sectors: energy, transport, agriculture, chemicals, materials, etc, and is the most complete and reliable database for the European context.
The ecoinvent database is hosted by the Swiss Centre for Life Cycle Inventories, a joint initiative of the Swiss Federal Institutes of Technology Zürich (ETHZ) and Lausanne (EPFL), the Paul Scherrer Institut (PSI), the Swiss Federal Laboratories for Materials Testing and Research (Empa), and the Swiss Federal Research Station for Agroecology and Agriculture (Agroscope FAL Reckenholz).

c) Aggregation of data at the European level

As the goal was to publish aggregated data for Europe and not comparatively from a country to another, all data are showed as a weighted average made on the volumes of gas consumed in each European country. Therefore, data published per step is the weighted average of each European country: the more a country consumes natural gas, the more its performances count in the LCA results and the more its suppliers' performances appear in the environmental balance.

The origin of the natural gas also influence the overall performance of natural gas consumed in Europe. It is therefore important to precise hypotheses of supply: supply statistics have been collected for the year 2004.

The following figure sums up the major natural gas trade movement from producing countries to Europe in % of the total consumption of natural gas in Europe in 2004 [16].

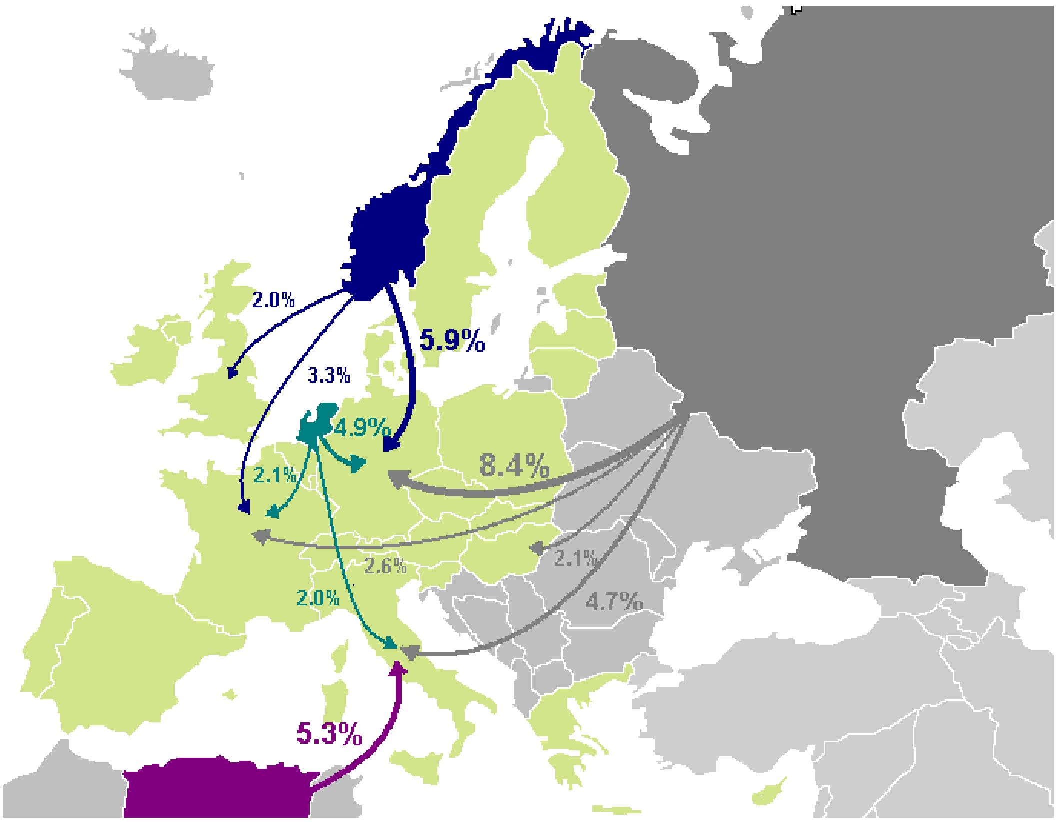

Figure 5: Main gas trade movements to and in Europe

→ About 25,8% of the gas consumed in Europe come from an indigenous production. In 2004, four countries in Europe consume their own gas production: Germany, Italy, the Netherlands and the

United Kingdom. The indigenous consumption in United Kingdom represents more than 17% of the natural gas consumed in Europe in 2004.

→ 15,1% of the gas consumed in Europe comes from imports from other European countries: this includes for example exports from the Netherlands to France.

→ 59,4% of the gas consumed in Europe comes from imports from non-European Union countries, including exports from Norway. From the 59,4% coming from non-European countries, 51,5% will be brought under gaseous form and 7,9% as liquefied natural gas (LNG): this includes for example exports from Algeria to France.

d) Overview of the collected data on the natural gas upstream chain – from production to distribution

The following table sums up the collected data for each step of the gas chain – excluding the final utilization phase -, in accordance with the data collection methodology explained in §2.3.a).

The main energy-consuming steps are:

	Production /Processing	International transmission by pipeline	Liquefaction
Global energy consumption	3%	5%	13,8%

Table 3: Detail on the most energy-consuming steps of the gas chain

→ **Liquefaction:** liquefaction occurs on LNG chains before the sea transport to the European gasification terminals. Liquefaction is an energy consuming process: natural gas is liquefied by compressing it at temperatures below its critical temperature. A big amount of natural gas is therefore used to drive the compressors and chill the gas to the temperature of minus 160°C. Currently operating liquefaction plants have an energetic consumption varying between 9% and 15%, depending on their age and other factors like external temperature for example.[1]

→ **International pipeline transmission:** the major impact of the transmission step comes from the combustion of natural gas in the compressor stations. To ensure that the gas is delivered to the customers at an adequate capacity, the pipeline pressure has to be raised roughly every 150 km. Another issue regarding long distance transmission is the accounting of fugitive emissions that occur on the network: one of the major sources of attacks concerning the environmental balance of natural gas is the question of the methane emission during transportation on the Russian export pipeline system. There are numerous studies published since 2000 on the methane emissions on the Russian transmission system, estimating the leakages rate on the whole pipeline system (about 6,000 km) between 0.36% and 3%. This LCA uses the values indicated by the Wuppertal Institut in 2005 [18], because it is the most recent data and stems from direct measurements of gas operators. Measurements have been performed on two parts of the Gazprom network. According to this study, fugitive emissions represent approximately 1% of the transmitted natural gas to the German border. Taking uncertainties into account, they also indicate a range of fugitive emissions rate between 0,6% and 2,4%[2]. On average, a molecule of natural gas consumed in Europe is transported 1,850 km via pipeline before reaching the border of the European consuming country[3]. Before liquefaction, natural gas has also to be transported from the production field to the liquefaction plant. On average a molecule of natural gas consumed in Europe is transported 404 km via pipeline to reach the

1 For Algeria, representing more than 50% of the LNG supplies in Europe in 2004, a Sonatrach publication on the LNG1 plant revamping project has been used [46]. Regarding Nigeria, Qatar and Oman, data have been collected from the IGU report "Natural gas - Toward a global life cycle assessment" [35].

2 This point being a highly sensitive issue in estimating the impact of the natural gas upstream chain, a sensitivity analysis has been performed to assess the impact of this choice on the final results.

3 This takes into account the fact that in some cases natural gas is produced and consumed in the same country. In this case, there won't be any international pipeline transmission step, but only a national transmission step

liquefaction unit. On average, the global energy consumption for pipeline transmission to Europe – including transmission to liquefaction units – is about 5%. It varies between 0,8% and 12,4% depending on the supply country: the more the production field is far away from the consuming country, the more the energy consumption is high.

→ **Production and processing:** data covers the whole production and processing steps that include natural gas dehydration and sweetening when necessary. Both steps were added because data are often not available for each individual step. Data coming from industry cover about 85% of the natural gas consumed in Europe[4]. Depending on the producing countries, the global primary energy consumption is close to 3% of the energy produced – from 0.8% to 3.9% for main countries. Main final energy consumptions and losses are due to the consumption of gas, diesel and electricity as fuels: 75%, 2% and 3% respectively, i.e. about 80% of the global energy consumptions. The flares represent about 15% of the energy consumptions depending on the countries (cf. §4.2). The fugitive emissions represent about 5% of the volume of produced gas. Depending on the country this share varies between 0.8% and 12%. Some chemicals are also consumed during theses steps: about 30 mg of chemicals is consumed per cubic meter of natural gas produced and processed. Theses chemicals are mainly Monoethylene glycol (about 70%), methanol (9%) and hydrochloric acid (9%). Hydrochloric acid is used for well treatment: this type of well stimulation consists of injecting acid into the well to open up the formation and allows the petroleum to flow through the formation more easily. Methanol is used to avoid freezing during gas extraction. Monoethylene glycol is consumed for natural gas dehydration.

	Sea transport	Gasification	National transmission	Storage	Low pressure distribution
Global energy consumption	1.4%	0.47%	0.27%	0.74%	0.68%

Other steps are less energy-consuming:

Table 4: Less energy-consuming steps of the gas chain

→ **Sea transport:** the technology considered in this study is the one used in the LNG tankers in 2004: they were powered by steam turbines using boil-off gas and heavy fuel oil with an average efficiency of 30% [51]. LNG chains are usually set up when it would cost too much to build pipelines because of the distance of transportation. Despite of this distance - 4300 km on average for the sea transport to Europe - , exporting LNG by tankers has not a major impact on the environment: the reduction in volume resulting from the liquefaction allows energy to be transported in a more environmental friendly way although both loaded and ballast voyages have been accounted for.

→ **Gasification:** gasification is a generally low impact process. Gasification is mostly obtained by exchanging heat between water taken from natural ecosystems (rivers, sea, etc). However, some energy consumption is needed sometimes for the pre-heating of this natural water and some complementary gasification equipments are used to gasify LNG through underwater combustion.

→ **National High pressure transmission:** national high-pressure transmission in Europe is the same process as international pipeline transmission; however distances of transmission within a country are way shorter, and the associated energy consumptions are thus lower.

→ **Storage in Europe:** the main impacts are due to the combustion of natural gas in turbines and motors used to inject natural gas in the reservoirs. Main final energy consumptions and losses are due to the use of natural gas in turbines and motors used to inject natural gas in the reservoirs: 86% of the energy is consumed to drive the compressors; the rest is used for processing the natural gas coming out of the storage – dehydration or sweetening of the gas coming out of the storage.

→ **Low pressure distribution in Europe:** low pressure distribution of natural gas requires little energy as it consists in dropping the pressure of the gas down. Main energy consumption source is therefore the losses of natural gas during maintenance of the distribution network.

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4 Sources: [20], (21], [22], [23], [25], [27], [29], [30], [31]

e) Overview of the collected data on the natural gas utilization phase

Eurogas-Marcogaz used figures collected for GDF SUEZ by the Paul Scherrer Institut in 2005. The Swiss Paul Scherrer Institut (PSI) with its Technology Assessment Group (GaBE) has a high international reputation as a Research Institute and is well known for its comprehensive expertise in LCA of energy systems. As one of its key activities in LCA it is responsible for energy systems in the world's leading LCA database ECOINVENT. Due to PSI's extensive knowledge and experience in LCA of natural gas conversion technologies for heat and electricity production, it proved to be an ideal partner for this project.

→ **Combined cycle power plant 800 MWe:** operating Natural Gas Combined Cycle (NGCC) plants is the most efficient and most environmentally sound way of electricity production on a large scale with fossil fuels today. A combined cycle consists of a gas turbine and a subsequent steam turbine, allowing very efficient use of the fuel. The net electric capacity of 800 MWe requires a combination of two units of 400 MW each, representing the commercial scale of large gas turbines of today. The overall electric efficiency of such power plants depends among other factors on the operation mode: base-load operation allows a yearly average net efficiency of 58%. Direct power plant emissions to the atmosphere are very low in comparison to the combustion of other fossil fuels like coal or oil. The characteristics of natural gas allow especially low SO_2 and particle emissions and therefore a reduction of damages to human health and ecosystems.

→ **Boilers 10 kWth and >100 kWth:** both boilers considered in our study are condensing and modulating units, representing state-of-the-art technology. While the small boiler for households is fuelled with natural gas at low pressure level, the bigger industrial unit is connected to the high pressure network. The yearly average efficiency of both boilers (for the whole lifetime) is 102% based on the lower heating value (LHV) of the natural gas. This figure corresponds to average yearly operation during the whole lifetime, i.e. operation under "real life" conditions. Regular maintenance of the boiler is assumed to take place in order to guarantee correct and high-efficient operation until the end of the lifetime.

→ **Several types of Combined Heat and Power (CHP) plants** in the range of 10-50 kWe are available on the market today. High environmental performance is one of the aspired characteristics of new installed units. Therefore, lambda-1-motor CHP plants with three-way-catalysts for emission reduction are chosen as reference technologies in this LCA. Condensing 30 kWe units are addressed. Electric and thermal efficiencies of these CHP plants are in a certain range adjustable, average figures of current state-of-the-art systems are chosen as reference values. The three-way-catalyst is installed in order to reduce NO_X emissions. The actual emissions depend on the mode of operation and – more importantly – on the performance of the catalyst, which in turn depends on its age.

→ **Stirling motor 1 kWe:** small Stirling motor CHP plants for individual households are an interesting option: they allow small scale electricity production at relatively low additional investment costs in combination with heat production. Advantages are the high global efficiency and material costs close to conventional gas boilers. A reference system condensing being available on the market by 2009 is analyzed.

For all utilizations, direct emissions of the system as well as chemicals and electricity consumptions for the auxiliaries were taken into account.

f) Building the gas chain

Once the data are collected for each step, it is necessary to build the whole gas chain.

In order to take the whole consumption into account, it is necessary, when assembling two steps, to consider that the natural gas consumed during the step "i" comes from the step "i-1".

For example, if the processing step has a natural gas consumption of $A_{Processing}$ = 1 + FL+V +GF, it has in fact a global consumption in primary energy equal to $A_{Processing}$ = (1 + FL+V +GF)* $A_{Production}$, where $A_{Production}$ is the natural gas consumption of the production step.

The following scheme illustrates this chain structure:

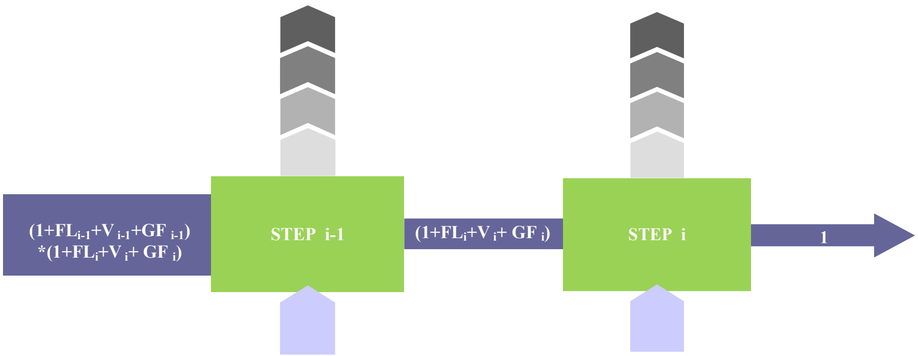

Figure 6: Assembly of two steps

When assembling N steps, the methodology is the same. The following scheme illustrates the structure of the chain:

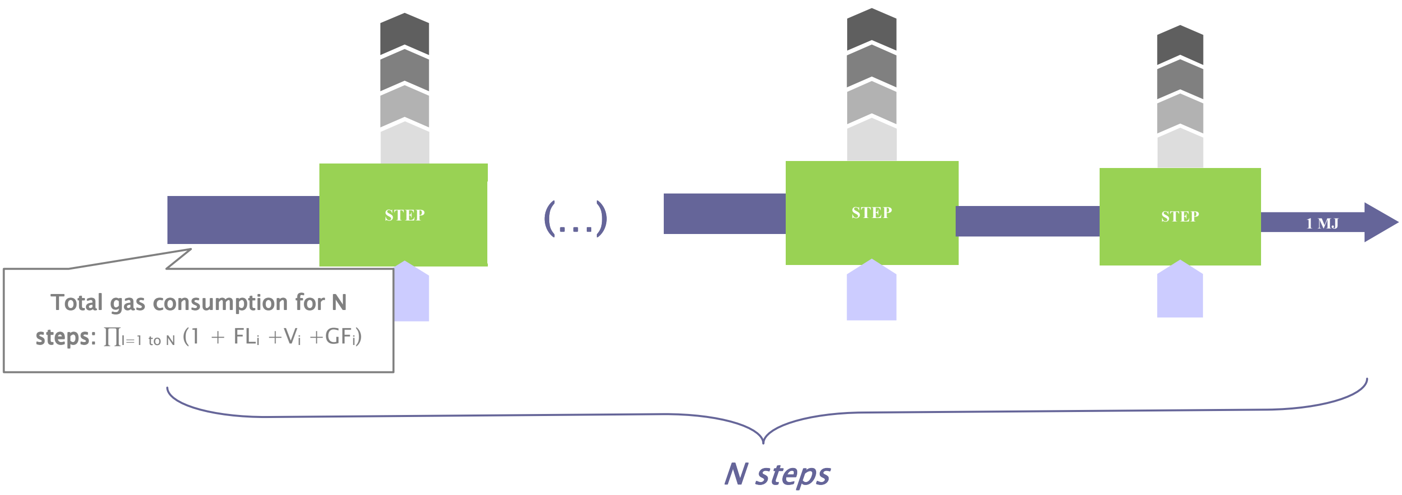

Figure 7: Assembly of N steps

The model has been build under a LCA dedicated software: Simapro 7.

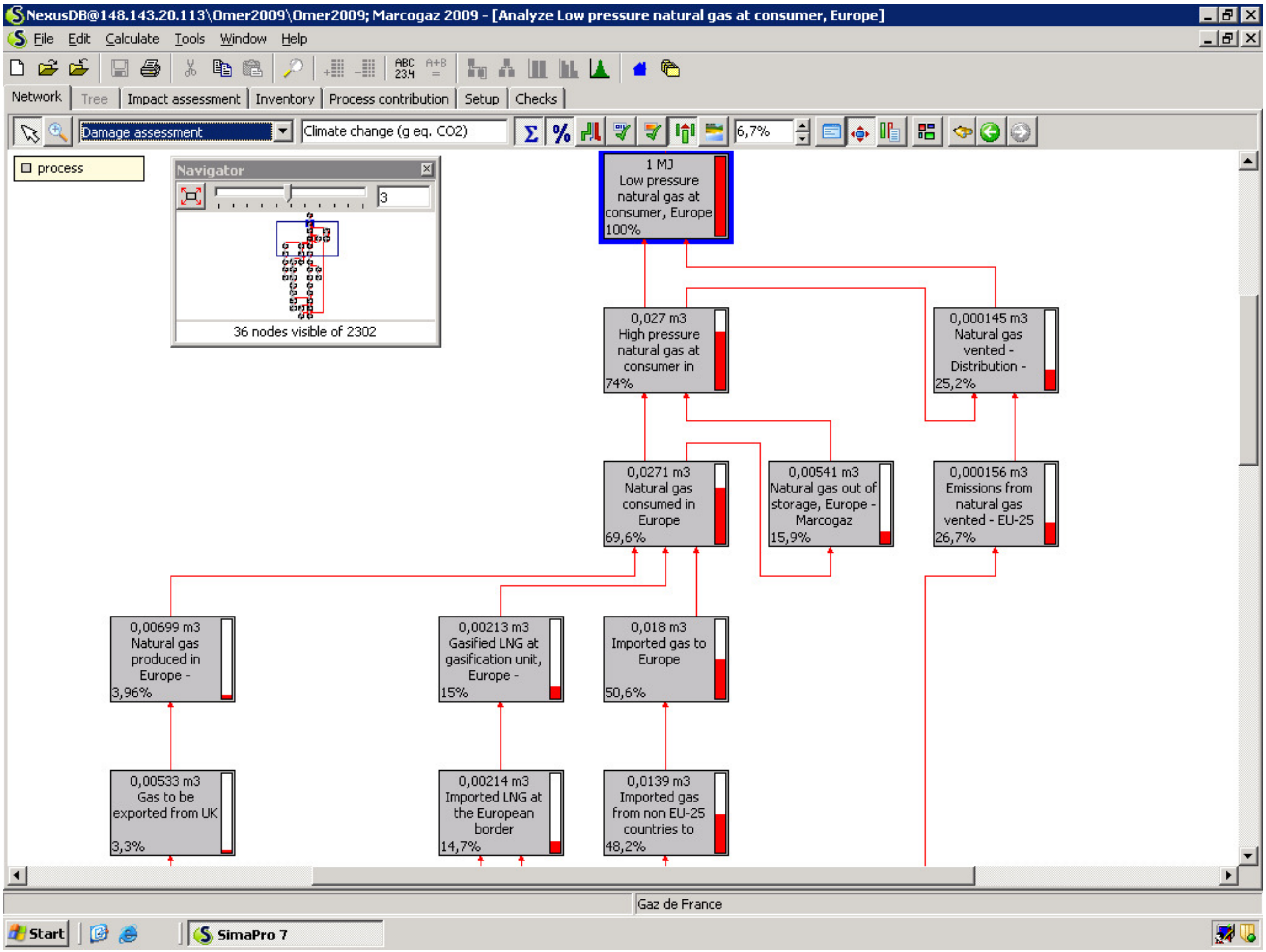

Figure 8: Modelling the gas chain with Simapro 7

3. RESULTS

3.1. Inventory results

The following tables present the overall inventory results for heat and/or electricity production with best available technologies (NGCC, condensing boiler for both domestic and tertiary use and CHP plant for both domestic and tertiary use) in an average place of consumption in Europe in 2004:

→ **Consumptions are expressed in primary energy consumptions** (primary energy from natural gas, primary energy from oil, primary energy from coal, etc.) per kWh of useful heat/electricity.
→ **Emissions are expressed in mass of component** (carbon dioxide, methane or nitrogen oxides) per kWh of useful heat/electricity.

Inventory by flow	Unit	Electricity, natural gas, at CHP 30kWe lambda=1, condensing	Electricity, natural gas, at Stirling microCHP	Electricity, natural gas, at combined cycle plant 800MWe	Heat, natural gas, at boiler condensing modulating >100kW	Heat, natural gas, at boiler condensing modulating 10kW	Heat, natural gas, at CHP 30kWe lambda=1, condensing	Heat, natural gas, at Stirling microCHP
CO_2	g CO_2	209	227	378	216	220	213	227
CO	mg CO	718	690	538	312	672	730	690
CH_4	mg CH_4	182	76,8	50,6	28,6	33,4	185	76,8
N_2O	mg N_2O	8,86	2,36	6,74	2,12	2,24	9,01	2,36
NO_x	mg NO_x	220	152	284	116	111	224	152
SO_x	mg SOx	31,5	61,6	57,7	38,9	51,3	32,0	61,6
Particulate matters	mg PM	2,60	12,4	6,99	4,35	7,55	2,65	12,4
NMVOC	mg NMVOC	64,5	71,7	78,6	39,6	69,6	65,6	71,7
Natural gas	kWh	1,05	1,11	1,88	1,07	1,08	1,06	1,11
Coal	kWh	0,005	0,007	0,007	0,004	0,005	0,005	0,007
Uranium	kWh	0,002	0,017	0,004	0,006	0,012	0,002	0,017
Oil	kWh	0,003	0,024	0,005	0,008	0,017	0,003	0,024

Table 5: Results of the inventory

Main sources of emissions are:

→ For CO_2 and N_2O: direct emissions are due to the combustion of natural gas in the conversion system (respectively 85% and 79%). These emissions are therefore mainly linked to the energetic efficiency of the conversion system. That is the reason why, electricity production in a NGCC emits more CO_2 per kWh electricity produced than the CHP: its overall efficiency reaches 58% whereas CHP units enable to reach much higher global energetic efficiencies.

→ For CH_4 and NMVOC: emissions occur on the natural gas upstream chain. About 50% of these emissions occur during the low pressure distribution phase in Europe. That is the reason why methane and NMVOC emissions are lower for systems directly connected to the high pressure transmission grid (Heat, natural gas, at boiler condensing modulating >100kW, Electricity, natural gas, at combined cycle plant 800MWe). NB: we have to bear in mind that CO_2 is by far the main substance contributing to climate change, accounting for about 95% of the GHG emissions, while methane emissions account for the remaining 5% (cf. § 3.2).

→ For SO_x and particulate matters: emissions are due to the electricity consumed as auxiliary in the conversion system produced from coal? (respectively 53% and 68%). These emissions are therefore greatly dependent on the European electricity production mix. The evolution of this mix will influence the emissions of the life cycle emissions of the natural gas conversion systems. The more a conversion system will consume electricity as auxiliary the more its emissions of particulate matters and SO_x will be high. For example, CHP condensing lambda 1 motor do not consume electricity from the grid, because it is using its own-produced electricity: as a consequence its emissions are lower than other heat production systems.

→ For CO and NO_x: emissions are due to both combustion phase and the natural gas upstream chain. These two flows can vary a lot between the systems: NO_x emissions are especially high for CHP condensing lambda 1 motors because of the choices made for renewal of the three-way-catalyst installed in order to reduce NO_x emissions. While a new catalyst reduces the NO_x emissions to 1 mg/m^3 (5% O_2), they are continuously increasing with the age of the catalyst till its replacement after about 5 years. This behaviour results in average NO_x emissions of 140 mg/Nm^3 (5% O_2). The base case considered has been chosen because it is a good compromise between exploitation costs and NO_x emission levels but NO_x emissions could be further reduced by changing the catalyst more frequently.

All energy consumptions, except for natural gas, are due to the production of electricity consumed as auxiliary in the conversion system. As for SO_x and particulate matters emissions, they are therefore greatly dependent on the European electricity production mix.

Natural gas consumption is mainly linked to the energetic efficiency of the conversion system.

Material consumptions, like lubricating oil or chemicals do not contribute to the flows considered.

The following figure illustrates the main emission and consumption sources for the production of heat in a domestic boiler in Europe in 2004:

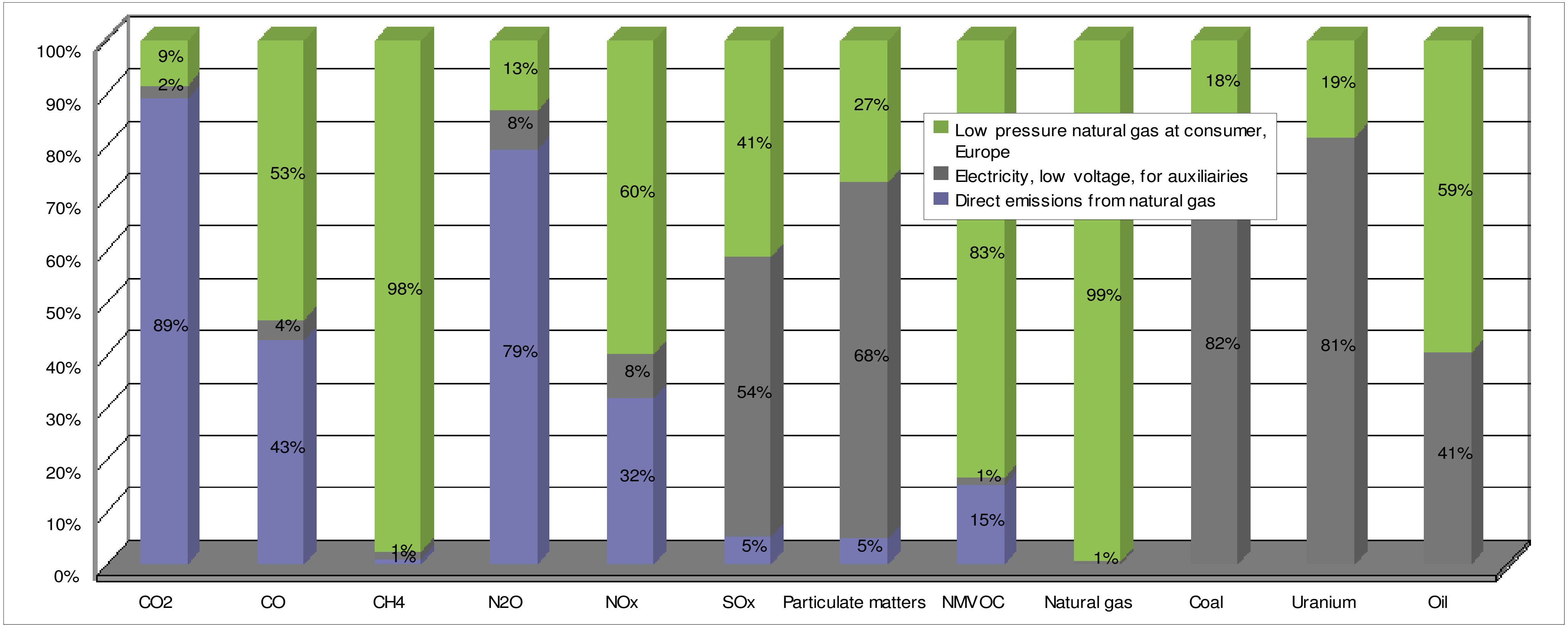

Figure 9: Inventory results for heat production in a domestic boiler

3.2. Impact assessment results

The following tables present the overall impact assessment results for heat and/or electricity production with best available technologies (NGCC, condensing boiler for both domestic and tertiary use and CHP plant for both domestic and tertiary use) in an average place of consumption in Europe in 2004:

For 1 kWh	GWP (g eq CO_2)	AP (mg eq SO_2)	Non renewable energy depletion (kWh)
Electricity, natural gas, at CHP 30kWe lambda=1, condensing	230	186	1..06
Electricity, natural gas, at Stirling microCHP	245	168	1..15
Heat, natural gas, at CHP 30kWe lambda=1, condensing	234	189	1.07
Heat, natural gas, at Stirling microCHP	245	168	1.15
Electricity, natural gas, at combined cycle plant 800MWe	394	257	1.90
Heat, natural gas, at boiler condensing modulating >100kW	225	120	1.09
Heat, natural gas, at boiler condensing modulating 10kW	237	129	1.12

Table 6: Summary of Eurogas-Marcogaz LCA results

Main sources of impacts are:

→ For global warming: the utilization phase (combustion at power plant or boiler) is predominant in terms of greenhouse gas emissions: its contribution exceeds 85% of the total GHG emissions. CO_2 is by far the main substance contributing to climate change, accounting for about 95% of the GHG emissions, while methane emissions account for the remaining 5%.

→ For acidification: the combustion (24%), the production of electricity used as auxiliary (22%) and the natural gas upstream chain (54%) are the steps contributing to this impact. NO_x emissions occurring during natural gas combustion in power plants and boilers and in compressor drivers (for liquefaction and pipeline transmission) account for about 80% of the acidifying emissions, SO_x emissions representing the 20% left. Those are mainly emitted during production/sweetening of the sour natural gas produced in Russia and Germany, as well as during LNG transport through the use of heavy fuel oil as propulsion energy.

3.3. Sensitivity analyses

a) Sensitivity to key data

One of the major sources of criticisms concerning the environmental balance of natural gas is the question of the methane emission during transportation on the Russian export pipeline system.

There are numerous studies published since 2000 on the methane emissions on the Russian transmission system, estimating the leakage rate on the whole pipeline system (about 6,000 km) between 0.36% and 3%. This LCA uses the values indicated by the Wuppertal Institut in 2005 [18], because they are the most recent data and stem from direct measurements of gas operators. Measurements have been performed on two parts of Gazprom network. According to this study, fugitive emissions represent approximately 1% of the transmitted natural gas to the German border. Taking uncertainties into account, they also indicate a range of fugitive emissions rate between 0.6% and 2.4%. This point being a highly sensitive issue in estimating the impact of the natural gas upstream chain, a sensitivity analysis has been performed to assess the impact of this choice on the final results.

Variation in the impact assessment relatively to the base case	Fugitive emissions rate in Russia and CEEC = 0,6%	Fugitive emissions rate in Russia and CEEC = 2,4%
Climate change	-0,8%	2,6%
Acidification	0,0%	0,1%
Non renewable energy depletion	-0,1%	0,3%

Table 7: Influence of the leakages rate in Russia on the overall performances for a domestic boiler

The choice of a specific leakage rate on the Russian export pipeline systems has a low impact on the final results: a sensitivity analysis showed that the use of the highest value found in the literature (0.43%/1000 km against 0.18%/1000 km for the baseline case) resulted in an increase of barely 2.6% of the total GWP.

Other sources of uncertainty are:

→ Compressor efficiencies in the Central and Eastern European countries (CEEC): in this study, Russia, Algeria, Arabic and African countries have been considered as less efficient, with ageing compressors and pipelines - according to Gazprom, the efficiency of its compressors lies between 24 and 28%. Central and Eastern Europe countries (CEEC) have been considered with a medium efficiency between 30 and 34%. This hypothesis could be underestimated. A sensitivity analysis has therefore been performed taking into account efficiencies of 24-28% also for CEECs.

→ Lack of representativeness concerning European data: representativeness of European data is sometimes weak. Representing on average 44% of the European market, sensitivity between maximum consumption and minimum consumptions has been performed.

The following table shows the results of the combined three sensitivity analyses on leakage rate of Russian export system, compressor efficiencies in the CEECs and European data:

Variation in the impact assessment relatively to the base case	**Minimum**	**Maximum**
Climate change	-2,0%	4,0%
Acidification	-1,7%	3,3%
Non renewable energy depletion	-0,5%	1,1%

Table 8: Confidence interval of the overall performances of a domestic boiler

The global confidence gap for the assessment of natural gas systems is therefore estimated to:

→ -2% and +4% for Global Warming Potential: the uncertainty is mainly due to the uncertainty on methane emissions on the Russian export system.

→ -1.7% and +3.3% for acidification.

→ -0.5% and +1.1% for non renewable energy consumption.

b) Sensitivity to the choice of impact assessment methods

Global warming potential (GWP) is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. It is a relative scale which compares the gas in question to that of the same mass of carbon dioxide. A GWP is calculated over a specific time interval and the value of this must be stated whenever a GWP is quoted or else the value is meaningless.

→ Reference year of GWP to be considered

The Intergovernmental Panel on Climate Change (IPCC) provides the generally accepted values for GWP, which changed slightly between 1996 and 2007.
Under the Kyoto Protocol, the Conference of the Parties decided that the values of GWP calculated for the IPCC Second Assessment Report are to be used for converting the various greenhouse gas emissions into comparable CO_2 equivalents when computing overall sources and sinks. That means that nowadays all Sustainable development reports refer to the IPCC 1996 factors. European regulation on GHG also uses these coefficients. Comparing our figures to the official ones first need to verify that the coefficients used are the same.

→ Time horizon to be considered

A substance's GWP depends on the timespan over which the potential is calculated. A gas which is quickly removed from the atmosphere may initially have a large effect but for longer time periods as it has been removed becomes less important. Thus methane has a potential of 25 over 100 years but 72 over 20 years; conversely sulphur hexafluoride has a GWP of 22,800 over 100 years but 16,300 over 20 years (IPCC TAR).

Commonly, a time horizon of 100 years is used by regulators. However, the European Platform recommends making a sensitivity analysis of the result including the time horizon 500 years in order to have an equal consideration of all GHG and especially the N_2O emitted by agriculture because it stays much longer in the atmosphere.

The following table sums up the various GWP that can be used:

	20 years			100 years			500 years		
CH_4	72	62	56	25	23	21	7,6	7	6,5
N_2O	289	275	280	298	296	310	153	156	170

Table 9: GWP values and lifetimes from 2007-IPCC, 2001-IPCC and 1996-IPCC

The following figure shows the influence of the choice of the GWP on the overall results for assessing the greenhouse gases of heat production in a domestic boiler:

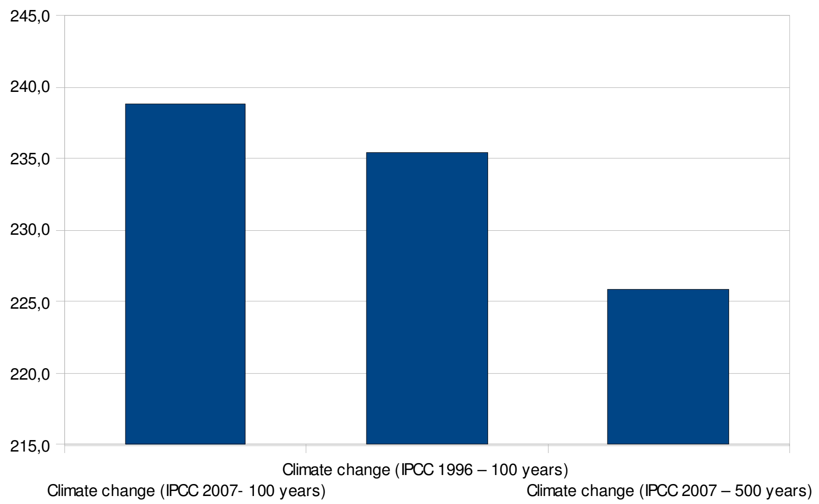

Figure 10: Assessment of GHG emissions of 1 kWh of heat produced in a domestic boiler according to three IPCC methods

The result of the sensitivity analysis shows that, depending on the chosen method, the overall results can vary significantly: when 1 kWh of heat produced emits about 237 g eq. CO_2 by applying IPCC-2007 GWP, the same system is credited of 235 g eq. CO_2 with IPCC-1996 and 226 g eq. CO_2 with IPCC-2007/horizon time 500 years GWP.

That shows the importance of clarifying the chosen GWP factors when assessing the greenhouse gases emission of a system.

4. Conclusions

4.1. The moderate differences between supply chains are mostly due to the difference of transmission distance

The supply chain of natural gas in Europe is very diversified. Three major supply chains are distinguished with specific particularities:

→ Europe – natural gas coming through short-distance pipelines from European countries (Norway, Great-Britain, Germany, the Netherlands)
→ Russia – natural gas coming through pipelines from the Siberian fields over thousands of kilometres
→ LNG – natural gas brought as LNG from various countries, mostly from Africa (Algeria, Nigeria, Egypt)

This LCA also allows assessing the environmental performances of the different supply chains of natural gas arriving to Europe[5]:

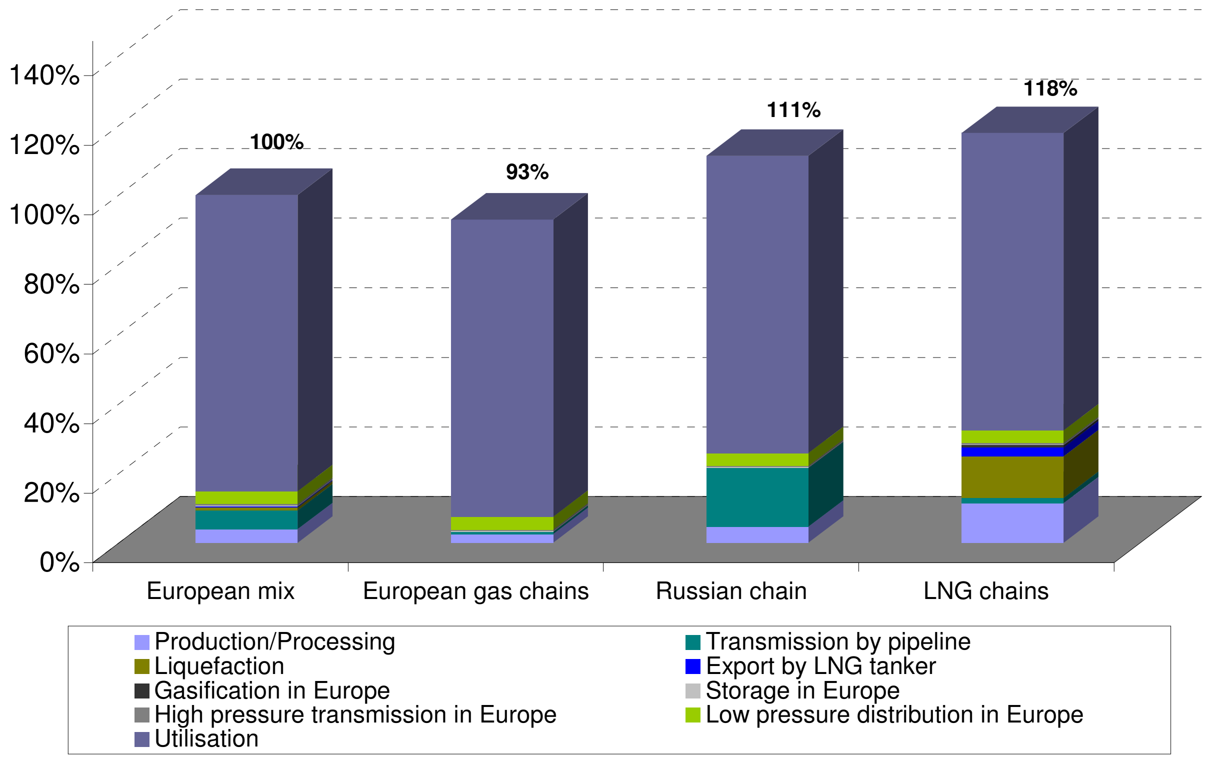

Figure 11: Comparison of GHG emissions per supply chain for heat production in a domestic boiler

→ The production of heat with a condensing boiler from natural gas coming to Europe as LNG emits about 27% more GHG than heat production with natural gas coming from European countries through conventional pipelines, mostly due to the high energetic consumption of existing liquefaction units and shows the strategic importance of investing production with natural gas coming from European countries through conventional pipelines.

→ Heat production from Russian natural gas emits about 20% more GHG than heat production with natural gas coming from European countries. This is mainly due to the distance covered from the

[5] European mix: mix of natural gas coming to EU-25 from all sources (Europe, Russia, Africa, etc.). Note: the results on the graph are normalized to 100% for the European mix.
European gas chains: mix of natural gas coming from Norway, Great Britain, Germany and the Netherlands to EU-25
LNG chains: mix of natural gas coming as LNG from Algeria, Qatar and Nigeria to EU-25
Russian chain: natural gas coming from Russia to EU-25

Siberian fields to EU-25 (about 5,000 km); in comparison, the distance covered from the European production fields is 500 km in average.

4.2. The four main priorities to improve the natural gas chain environmental performances

→ **Development of high efficiency gas utilizations:** the utilization phase plays a key role in the overall performances of the natural gas systems. By developing new applications with higher efficiency rates (heat pumps, micro-CHP and natural gas combined cycle), the natural gas industry is promoting its energy.

→ **Improvement of liquefaction units' efficiency:** on LNG chains, the main improvement to prioritize is the liquefaction step and the gas industry is massively investing in high efficiency liquefaction units. Currently operating liquefaction plants have an energetic consumption varying between 9% and 15%, depending on their age and other factors like external temperature for example. However, the future liquefaction units will be much more efficient, like the Snøhvit liquefaction plant started in 2008, whose energetic consumption is about 6%.

→ **Improvement of compressor efficiencies during long distance transmission:** the new projected pipelines as well as the programs on the reconstruction and technical upgrading of existing gas transmission facilities will allow to improve the environmental performances of long distance chains. The gas industry makes significant investments in such programs: in Russia, annual investments in the reconstruction of gas compression units until 2030 are evaluated to be more than USD 2 billion [65].

→ **Reducing gas flaring during production on associated fields**: flaring during natural gas production is not a common practice. The flaring rate during gas production on associated gas and oil fields is generally situated between 0,1 and 0,5%. However, this percentage in much higher for Nigeria[6]. In spite of a ruling by the Federal High Court of Nigeria that forbade flaring in 2005, gas flaring is still frequently used at current time.

4.3. A need for specific and up-to-date data to be considered in European regulations

The results of Eurogas-Marcogaz LCA confirm the good performances of natural gas as a fuel. Generally the results support the figures used in existing generic LCA databases for global warming and non-renewable energy resources depletion although both impacts are slightly lower in this study.

However, important differences with existing generic LCA databases have been noticed on certain flows, particularly for CH_4 and SO_x emissions, which are generally overestimated in the upstream chain.

→ Methane emissions on the transmission and distribution grids are much higher in existing database than the rates measured on the networks of different European companies. This results in a reduction by a third of total methane emissions associated with the domestic systems assessed in this study.

→ Moreover the ecoinvent model for the European natural gas supply was based on a share of sour gas of 10.2%, representing the average European supply in 2000. However, in 2004, the estimated part of sour gas only reached 3.4%. This explains that the domestic systems assessed in this study emit less SO_x on their whole life cycle than the corresponding systems in the ecoinvent database.

Other issues are:

→ Focussing on the right priorities: for some emissions – SO_x and particulate matters for example -, the main source of emission is not the natural gas used but the electrical auxiliaries needed for the working of the conversion system. Such distinctions have to be made in the regulations.

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6 Data used in this study were taken from two different companies operating in Nigeria [5]. These data concern mainly onshore production in the Niger delta and a small part of offshore production, both associated production of oil and gas. According to theses sources, about 10% of the natural gas produced is flared. In fact, 10% of the global energy produced on the production field is flared and have been allocated to both oil and gas production.

→ Using unified methodology for assessing the GHG: as seen in § 3.3.b), comparing figures to the official ones need first to verify that the coefficients used are the same, especially for GWP.

These differences show the importance not to base environmental decisions on generic databases without first assessing their relevance and applicability.

However, the reader should pay attention that no direct comparison should be made between the different systems because of the differences of scale and type of use: a micro CHP does not provide the same amount of electricity as a natural gas combined cycle.

5. Perspectives

5.1. A study to be updated …

This study allowed to quantify LCA results specific to the European context and showed the limitations of using generic European LCA databases for national policies.

However, this context is evolving fast: since the launching of the working group in 2004, the political borders of Europe have been extended to 27 countries and the providing sources are changing as well as the gas operators. Our figures from 2004 have evolved since and will evolve in the future.

An annual update of this LCA should be made in order to follow the evolution of both origin of natural gas supplies and environmental performances in the whole gas chain.

5.2. … completed …

In the future, other essential flows will be included to allow a more comprehensive evaluation of the environmental performance of natural gas systems. The current scope of the study guarantees the quality of the results for the three considered impact categories but also limits the use of our data: the comparison with other energy carriers is limited to only three indicators and excludes some essential aspects like for example eco-toxicity, waste (inert, radioactive…), or ozone depletion.

5.3. … and reviewed

The ISO standards recommend making a peer review. A critical review is a process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment. This peer review will be subcontracted by the end of 2009.

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