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LCA OF THE EUROPEAN GAS CHAIN: CHALLENGES AND RESULTS

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1. ABSTRACT

The Eurogas–Marcogaz Joint Group on Health, Safety & Environment has set up a working group on LCA, with the aim to assess the environmental footprint of the whole European natural gas chain, including the final utilization, by means of a Life Cycle Assessment (LCA).

This study presents a detailed analysis of the environmental performances of natural gas as a fuel for three impact indicators (climate change, terrestrial acidification and depletion of non renewable energy resources). The aim of this study is to give data, validated by the European Gas Industry, concerning the environmental performances of the natural gas chain in order to:

- improve the knowledge of the natural gas chain contribution,
- identify the main contributors,
- and identify solutions for improvement.

Despite improvements already achieved along the gas chain since several years, it could be further refined by:

→ Developing high efficiency gas conversions systems.
→ Improving the efficiency of liquefaction units which is a main issue for LNG chains,
→ Improving compressor efficiencies for long distance transmission,
→ Reducing gas flaring during production on associated fields,
→ Reducing leakages along the transport and distribution pipelines.

The results presented here may also be used to identify further actions, including at a regulatory level. For example, some emissions (such as SO_X) are not due to the natural gas itself but to the use of electrical auxiliaries of the conversion systems. Such distinctions could be made in relevant regulations.

This study allows to quantify LCA results specific to the European context and shows the limitations of using generic European LCA databases for National policies. Since the launch of the Working Group in 2004, the political borders of Europe have been extended to 27 countries and several mergers have taken place in the Gas Industry. Along with these changes, some progresses have been made from a technological point of view (e.g. diesel-electric engine instead of steam turbine for LNG carriers). An update of this LCA should thus be undertaken in order to keep up with the evolution of both technologies used along the natural gas chain.

In the future, other essential impacts will have to be included for a more comprehensive evaluation of the environmental performance of natural gas systems, in order to enlarge the current scope to other environmental impact indicators. A critical review has been done on this study, certifying that the LCA conducted complies with the requirements of the ISO standards 14040 and 14044.

TABLE OF CONTENT

2. CONTEXT AND OBJECTIVES

2.1. A REFERENCE LCA FOR THE EUROPEAN NATURAL GAS INDUSTRY

The current context is characterized by the development of life cycle oriented regulations and by the launching of the "International Reference Life Cycle Data System" (ILCD) project supporting business and policy making in Europe and worldwide with reference data and recommended methods on Life Cycle Assessment (LCA) [1]. In this context, the Eurogas–Marcogaz Joint Group on Health, Safety & Environment [2] has set up a working group on LCA. Its first task, which started in 2004, was to calculate the environmental footprint of the whole European natural gas chain, including the final utilization, by means of a Life Cycle Analysis (LCA).

The aim of this study is thus to give data, validated by the European gas industry, concerning the environmental performances of the natural gas chain in order to:

- improve the knowledge of the natural gas chain contribution,
- identify the main contributors,
- and identify solutions for improvement.

The results of this Eurogas–Marcogaz study may be used by LCA experts to model the gas chain in the EU-25.

In accordance with ISO 14040 and in order to ensure the credibility of the study, a peer review of this LCA has been performed [3].

2.2. THREE MAIN NATURAL GAS UTILIZATIONS ASSESSED

The scope of this study covers all steps of the natural gas chain, from production to utilization [4]. The natural gas applications addressed are the following:

- Electricity production with natural gas combined cycle power plants,
- Heating with condensing boilers (for domestic or industrial use),
- Combined heat and power production (for domestic or commercial buildings).

2.3. IMPACTS EVALUATION

The LCA is focused on three environmental impacts :

- Climate change (IPCC 2007 methodology, 100 years horizon), with CO_2, CH_4, and N_2O emissions,
- Terrestrial Acidification (ReCiPe 2008 methodology, Hierarchist scenario), with NO_X and SO_X emissions,
- Non renewable energy use (as Cumulated Energy Demand): natural gas, oil, coal, and uranium.

3. DESCRIPTION OF THE NATURAL GAS CHAIN: FROM REALITY TO THE PRACTICAL MODELLING IN LCA

3.1. METHODOLOGY USED FOR THE MODELING OF THE GAS CHAIN

This LCA includes all relevant phases of the natural gas chain, from natural gas extraction to the final use for energy production. It includes long distance transmission by pipelines and LNG tankers, liquefaction, gasification, national transmission and distribution of the natural gas. The manufacturing and laying of infrastructures and equipment have been excluded.

The same approach has been used for data collection and modeling at each step as described Figure 1. Data collected at each step include:

- Consumption of natural gas for internal energy use of a given step,
- Diesel and heavy fuel oil consumption,
- Electricity consumption,
- Other material consumptions such as water, chemicals, etc.,
- Natural gas flared,
- Natural gas vented or fugitive emissions.

At each step, the inventory is calculated following the same methodology, i.e.:

- Each energy input flow is expressed as a percentage of energy produced by the step.
- Vented gas rates are deduced from methane emission levels where no data are available directly on the total volume of gas vented.
- Emission factors are taken from data collected on-site if available, or deduced from energy consumptions if not.
- Data collected for non energy input flows (chemicals in particular) are completed with the corresponding life cycle inventory.

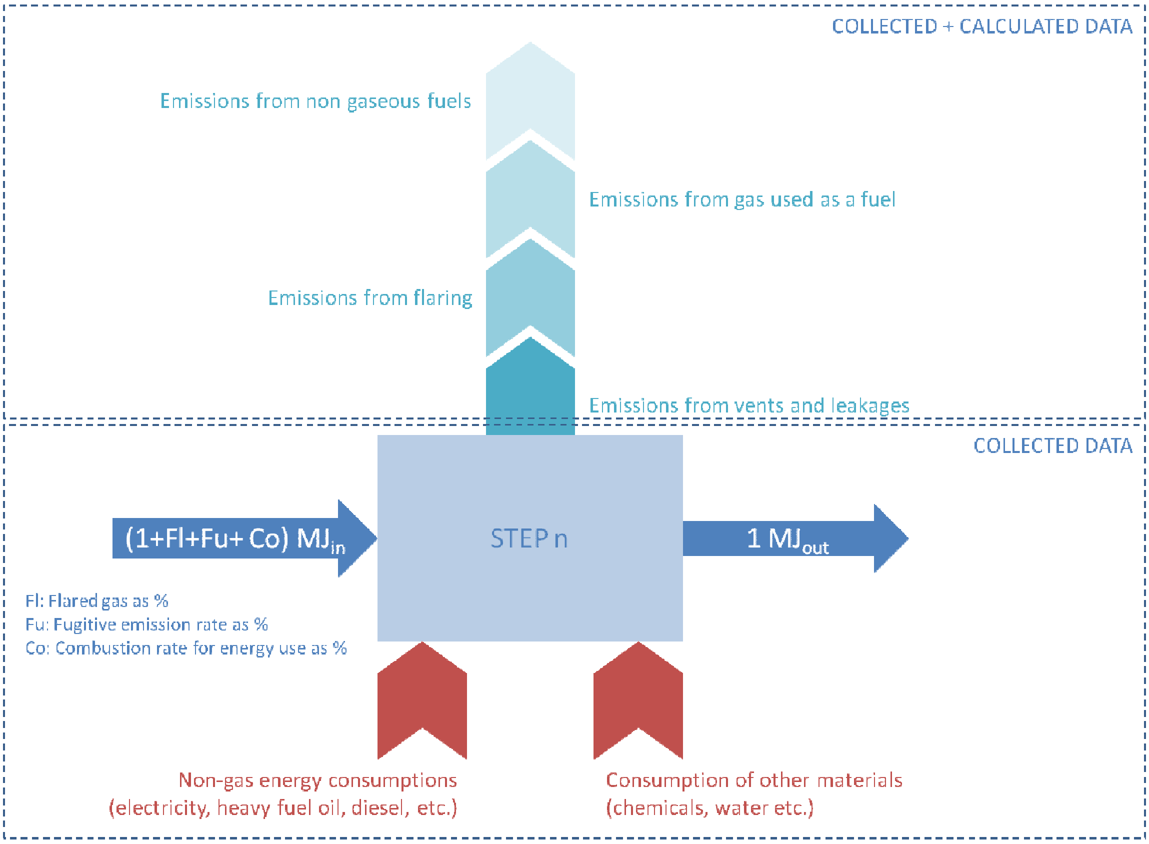

Figure 1 - Modeling of a given step in the natural gas chain

3.2. GEOGRAPHICAL AND TIME REPRESENTATIVENESS

The geographic borders of the study are those relative to the supply chain of EU-25. Data are representative of 2004, when the study was launched. However, a sensitivity analysis was performed to estimate the influence of a modification of the natural gas supply in Europe, in order to ensure that the results are still relevant.

3.3. COMPARISON WITH THE ACTUAL GAS CHAIN

A lot of different steps are necessary to supply the natural gas from the gas in ground to the final consumer in Europe. At each individual step, environmental impacts may be different, depending on:

- The area, because of various geological, physical, climate or even regulatory conditions,
- The technology implemented,
- The industrial operator at a given site or plant.

Because all data are not available to describe in detail the environmental impacts of each actual step of the natural gas chain, the modeling used in the LCA is based on various assumptions and simplifications, as described by Figure 2. This figure shows the limits of the current modeling and possible improvements in particular in terms of technical and geographic representativeness of the LCA.

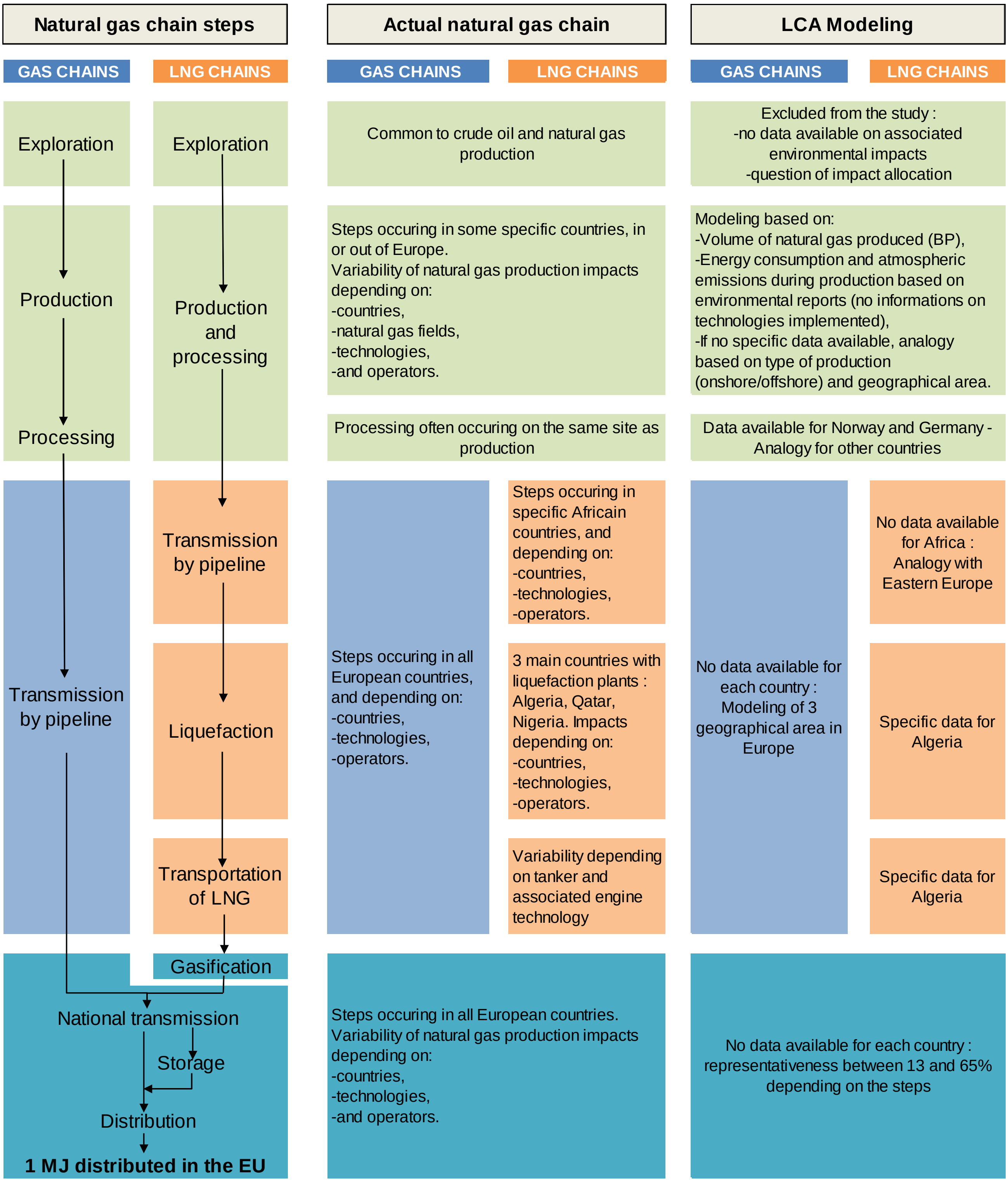

Figure 2 - Comparison of the modeling used for the LCA with the description of the actual processes involved in each step of the natural gas chain

4. RESULTS
4.1. RESULTS FOR THE UPSTREAM CHAIN

Table 1 presents the results of the impact assessment applied to the natural gas chain until the distribution, per MJ of natural gas delivered (excluding the final use). The difference between high and low pressure natural gas comes from methane emissions and energy consumption at the final distribution step, with associated impacts in terms of climate change and non renewable energy depletion.

GHG emissions reach 7.39 g $CO_{2\ eq}$/MJ for high-pressure natural gas and 10.1 g $CO_{2\ eq}$/MJ for low-pressure natural gas. Carbon dioxide is the main substance responsible for global warming, representing 71% of the GHG emissions associated to high pressure gas and to 53% of the GHG emissions associated for low pressure natural gas. Methane is the second flow contributing to global warming, whereas N_2O emissions are negligible.

Acidifying emissions reach about 15 mg eq. SO_2 for both high and low pressure natural gas, SO_X representing 27% of the acidifying emissions and NO_X 73%.

Energy consumption varies between 99 kJ of energy surplus/$MJ_{energy\ transmitted}$ for high-pressure natural gas and 107 $kJ_{surplus}$/$MJ_{energy\ distributed}$ for low-pressure natural gas. Natural gas is the main fossil resource used, representing approximately 92% of the global energy consumption. Uranium and oil represent each 2.8% of the non-renewable energy resources utilization.

Impact per MJ of natural gas	Unit	High pressure natural gas distributed in Europe	Low pressure natural gas distributed in Europe
Non renewable energy depletion	kJ surplus*	98.6	107
Climate change	g eq. CO_2	7.39	10.1
Acidification	mg eq. SO_2	14.3	14.6

Table 1 - Impact assessment results for the natural gas distributed in Europe in 2004

* kJ surplus means the additional energy required to produce 1MJ of natural gas

More in depth comments on the impacts of the upstream chain can be made by looking at the detailed results step by step (Figure 3).

The production step and the long-distance transport of natural gas by pipeline have a large contribution to each of the 3 impacts assessed, because of energy consumed (and thus associated atmospheric emissions) and leakages occurring at those steps.

Steps occurring in Europe do not have a large impact on climate change except for the distribution phase. This latter represents about 25% of the total GWP of natural gas distributed in Europe: this is mainly due to methane emissions and to a more limited extent to energy used for intermediary compression as natural gas or electricity. However there is an uncertainty associated to this step, as available data are not always representative of each Country considered.

The two main step contributing to non renewable primary energy depletion are the production of natural gas and the long distance transmission by pipeline. Impact associated to the natural gas transport by pipeline is due to the additional energy (including electricity) used for compression (2 to 2.8 MJ/MJ for 1000 km) and to methane leakages.

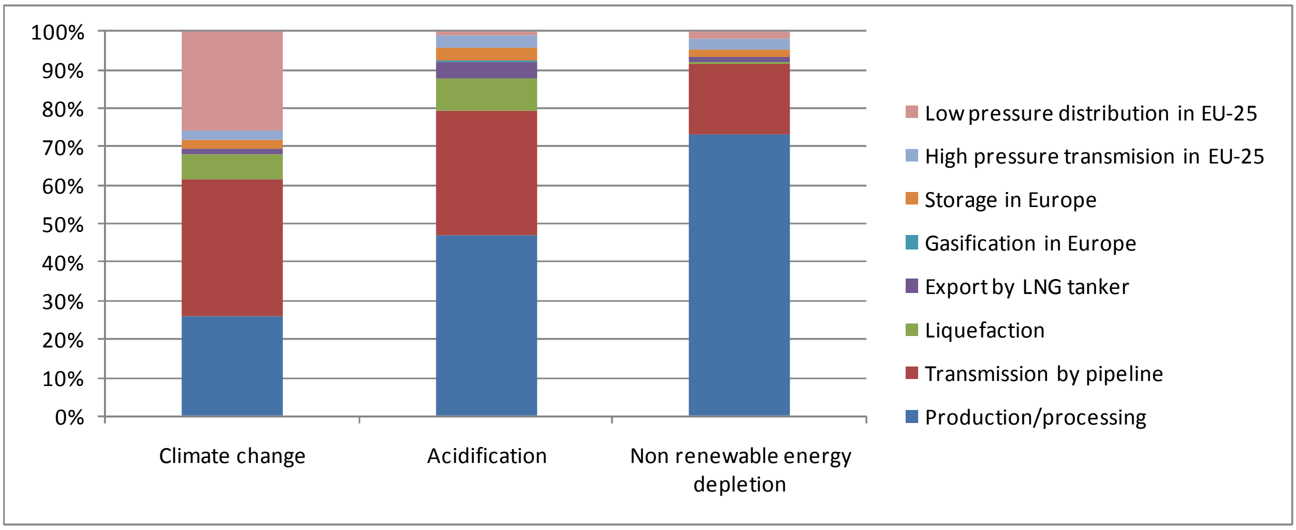

Figure 3 - Contribution of the various steps of the upstream part of the natural gas chain to global warming, non renewable energy depletion and terrestrial acidification

65% of natural gas supplies (produced in Europe and transported by pipelines from close regions) account for 15% of the GWP of the natural gas distributed in Europe. This low contribution can be explained by the limited transmission distances from production fields to European borders as well as by the overall performance of European natural gas networks and facilities. Russia and LNG chains, representing 27% and 8% of the supply, have a major impact on global warming: respectively 40% and 15% of the GWP. Both long transmission distance from Russia (more than 5,000 km) and the high energy consumption rate of liquefaction units are responsible for the high contribution of the chains considered. However high uncertainties remain on data related to leakages thus having consequences on the global uncertainty of the results.

The variability of impacts, in terms of GHG, associated to the main different supply chains involved is shown Figure 4 (European mix set at the reference).

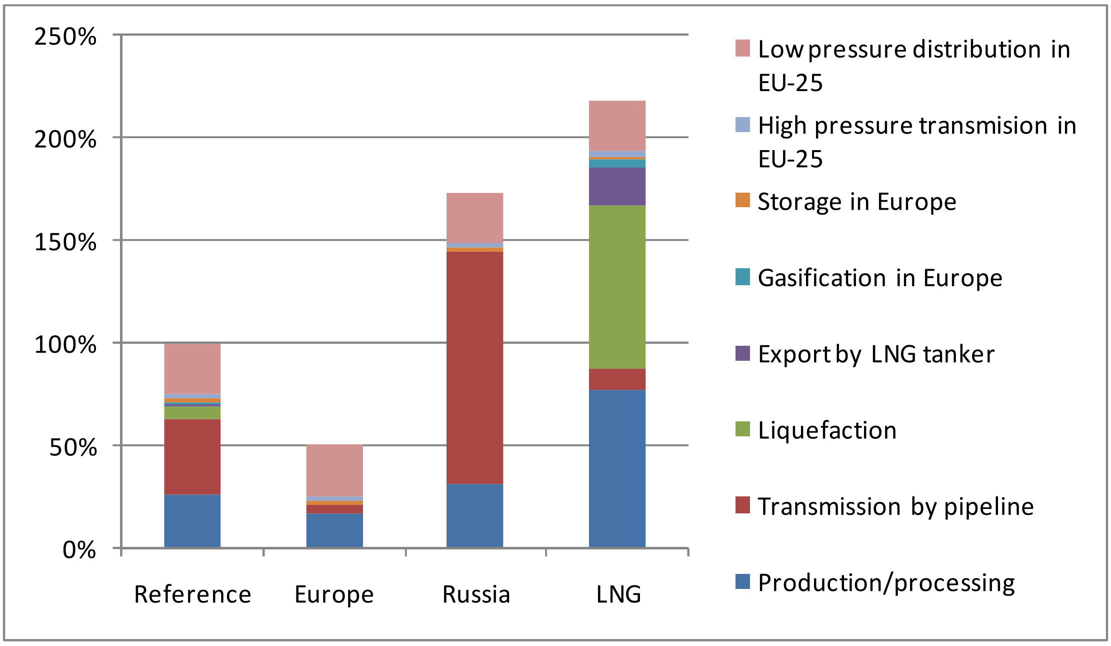

Figure 4 - Comparison of the repartition of GHG emissions along the upstream chain depending on the supply chain

As for GHG emissions, 62% of natural gas supplies (produced in Europe and coming by pipelines) account for only 16% of the acidification potential of the natural gas distributed in Europe. Russia, Germany and LNG chains, representing 27%, 4% and 8% of the supply, have a major impact on acidification: they respectively contribute to 50%, 6% and 21% of the acidification potential. SO_X emissions, usually low for the gas industry, are due to the processing of sour gas in Russia and Germany and to the use of fuel oil in LNG carriers.
Again, steps occurring in Europe do not have a large impact on acidification: they contribute to about 7% of the total acidification potential.

4.2. RESULTS FOR THE WHOLE CHAIN, INCLUDING FINAL USE

Table 1 presents the results of the impact assessment applied to the natural gas supply chain including the final use, expressed per kWh of final energy produced (heat or electricity) for the different conversion systems included in the study.

For 1 kWh produced	Climate Change ($g\ CO_{2eq}$)	Terrestrial Acidification ($mg\ SO_{2eq}$)	Non renewable energy depletion (kWh) as total primary energy
Heat at boiler – Domestic use	238	96	1.12
Heat at boiler – Industrial use	225	87	1.09
Heat at CHP – Domestic use	245	126	1.15
Heat at CHP – Tertiary buildings	232	140	1.07
Electricity at CHP – Domestic use	245	126	1.15
Electricity at CHP – Tertiary buildings	232	140	1.07
Electricity at combined cycle power plant	393	180	1.90

Table 2 - Summary of Eurogas-Marcogaz LCA results for natural gas systems in Europe in 2004

For a given type of final energy, the differences observed on the environmental impacts are mainly linked to the efficiency of the conversion process and to the type of combustion of natural gas (in particular for NO_X emissions). In the case of CHP, the results are the same for heat and electricity because allocation of impacts is based on the final energy produced.

Figure 5 details the contribution of the various steps of the life cycle to the three impacts assessed. The utilization phase (combustion at power plant or boiler) is predominant in terms of GHG 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%.

Regarding acidification, the utilization phase and the upstream chain both have a significant contribution on the acidification potential. During the utilization step, almost 25% of the emissions are due to the combustion process by the natural gas appliances, the electricity for auxiliaries (where existing) amounting to ~25% of the total emissions. NO_X emissions occurring during natural gas combustion in power plants and boilers as well as in compressor drivers for liquefaction and pipeline transmission account for about 65% of the acidifying emissions, SO_X emissions representing the 35% left.

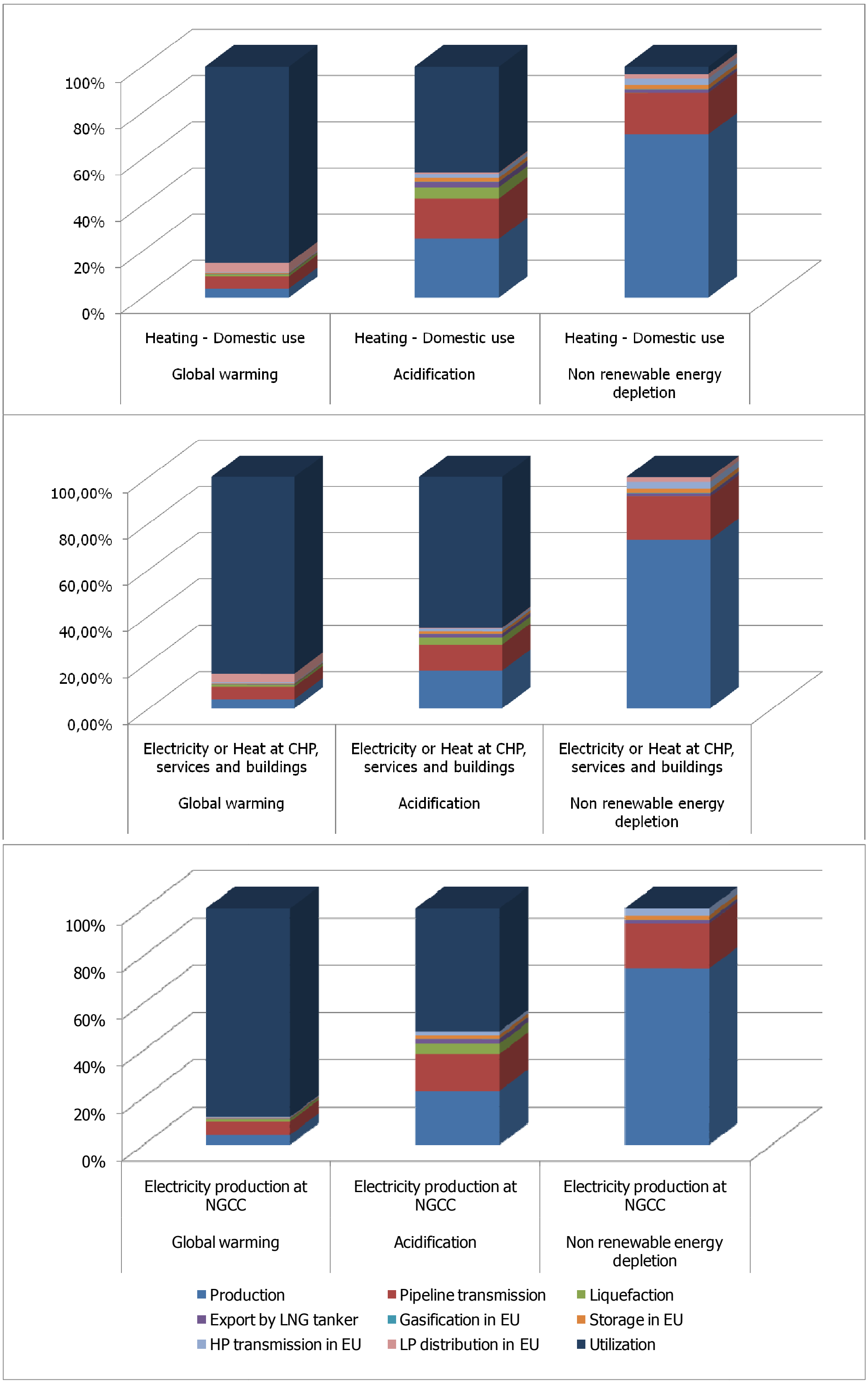

Figure 5 - Contribution of the various steps of the natural gas chain to global warming, non renewable energy depletion and terrestrial acidification for the three uses studied.

The main differences between the 3 uses are related:

- To acidification, because mainly of differences in conversion efficiency of the final use and associated NO_X emissions factors.
- To the contribution of the LP distribution step for domestic and tertiary uses, to a more limited extent.

5. SENSITIVITY ANALYSIS

5.1. IDENTIFICATION OF SENSITIVE PARAMETERS

During the inventory phase, several parameters were identified as sensitive:

- One of the major sources of concern regarding the environmental balance of natural gas is the question of **methane emissions rate on the Russian export pipeline system during transportation** from Russia to the EU borders. The present LCA uses the values indicated by the Wuppertal Institute in 2005 [5] as baseline case, based on direct measurements on Russian networks.

- The **global auto consumption rate during sweetening process in Germany**: A global auto consumption rate of 2.697% has been considered as deduced by ecoinvent from BEB data [6].

- **Compressor efficiencies** in the Central and Eastern European countries (CEEC): in this study, the infrastructures in Russia, Algeria, Middle-Eastern and African countries have been considered as less efficient, with ageing compressors and pipelines - the efficiency of its compressors has been considered between 24 and 28%. A sensitivity analysis has therefore been performed taking into account efficiencies of 24-28% for CEECs as well.

- Representativeness of **European data** is sometimes weak. Representing on average 44% of the European market, sensitivity analyses on the data concerning the steps taking place in Europe (gasification, storage, national transmission and distribution) has also been performed to assess its influence on LCA overall results.

The values of each sensitive parameter taken into account are summarized in Table 3.

	Base Case	Value min	Value max
Methane leakage rate on the Russian export pipeline system	0.18%	0.11%	0.44%
Global autoconsumption rate during sweetening process in Germany	2.697%	2.697%	5.95%
Compressor efficiencies in CEECs	2.30%	2.30%	2.84%
Gasification			
→ Vents	0.009%	0.006%	0.013%
→ Fuel gas consumption	0.38%	0.288%	0.676%
→ Grid electricity consumption	0.078%	0.051%	0.085%
Storage			
→ Vents	0.105%	0.037%	0.108%
→ Fuel gas consumption	0.494%	0.197%	0.511%
→ Grid electricity consumption	0.141%	0.130%	0.339%
National transmission			
→ Vents	0.019%	0.010%	0.031%
→ Fuel gas consumption	0.237%	0.151%	0.491%
→ Grid electricity consumption	0.012%	0.006%	0.025%
Distribution			
→ Vents	0.539%	0.418%	0.640%
→ Fuel gas consumption	0.122%	0.033%	0.187%
→ Grid electricity consumption	0.021%	0.006%	0.027%

Table 3 - Summary of the sensitivity analysis performed

5.2. SENSITIVITY OF THE RESULTS ON THE UPSTREAM CHAIN

Results of the global sensitivity analysis on the upstream part of the natural gas chain are given in Table 4. The global confidence gap on the upstream chain is relatively high:

- The choice of a specific leakage rate on the Russian export pipeline system has potentially a large influence on climate change results: considering a rate of 0.44%/1,000 km results in an increase of 18% of the burden on climate change compared to the baseline case (0.18%/1,000 km) as methane has an impact 25 higher than the CO2 on climate change. The energy depletion varies accordingly to the leakage rate as the natural gas lost has to be produced in the first place, but to a much lesser extent than climate change results. The low representativeness of data collected for the steps occurring in Europe affects significantly the results in terms of GHG emissions and energy consumptions because of the large variations in the energy consumptions (between -14% and +27%). Regarding the acidifying emissions, they vary with the electricity consumptions as coal and oil are used in the European electricity mix (respectively 36% and 5%).
- The acidification results are finally slightly dependent on the global auto consumption rate during the sweetening process: they increase by less than 10% when the auto consumption rate doubles. Indeed, when the global auto consumption increases, the part of sour gas burned increases as well. This results in higher NO_X and SO_X emissions, knowing that NO_X emissions contributes to around 65% of the total impact, and SO_X emissions to around 35%.
- On the contrary, compressor efficiency in the Central and Eastern European countries is not a critical parameter (differences below 2%).

	Min	Max
Climate change	-14%	+28%
Acidification	-3,4%	+14%
Non renewable energy depletion	-5,8%	+13%

Table 4 - Global confidence gap of the results associated to low pressure natural gas

5.3. SENSITIVITY OF THE RESULTS ON THE WHOLE LIFE CYCLE, INCLUDING FINAL USE

Uncertainties are significantly lower when the utilization step is taken into account, as shown in Table 5.
After the utilization step, the influence of the parameters studied is much lower on results: uncertainties range between -2% and +4% compared to the baseline scenario. The results in terms of climate change, acidification and non renewable energy depletion can therefore be considered as reliable.

	Min	Max
Climate change	-2.1%	+4.2%
Acidification	-1.8%	+7.5%
Non renewable energy depletion	-0.5%	+1.2%

Table 5 - Global confidence gap of the results associated to the final use of natural gas

5.4. SENSITIVITY ON THE NATURAL GAS SUPPLY

The results show that variations in supply quantities and origins have not an important impact on climate change and acidification. Concerning non renewable energy depletion, the variation expressed for the total energy consumed is of the same order of magnitude.
The slight variation can be explained by the large geographic border followed by this study. The main differences are the increase of LNG part (+50%), the increase of natural gas supply from Norway (+26%) and the decrease of natural gas supply from Russia (-9%). Thus, these variations compensate each other.

This sensitivity analysis shows that the results of the study are still representative of the environmental impacts of the natural gas chain in Europe in 2009 even if data relate to 2004.

Impact category	Unit	2004	2009	Variation 2004/2009
Climate change	g CO_{2eq}/MJ	10.04	10.03	-0.1%
Acidification	mg SO_{2eq}/MJ	14.58	14.96	2.6%
Non renewable energy depletion	*$kJ_{surplus}$/MJ*	*107*	*120*	*12.9%*
	MJ_{total}/MJ	1107	1120	1.2%

Table 6 - Variation of the results between 2004 and 2009 linked to the difference of supply

6. CONCLUDING REMARKS

Eurogas–Marcogaz LCA results present a detailed analysis of the environmental performances of natural gas as a fuel for three impact indicator. Despite improvements already achieved along the gas chain since several years, the natural gas results could be further improved by:

- → **Developing high efficiency gas combustions systems**: Indeed, the utilization phase accounts for more than 85% of the GHG emissions and about 50% of acidifying emissions.
- → **Improving the efficiency of liquefaction units** which is main issue for LNG chains. Currently operating liquefaction plants have an energetic consumption ranging between 9% and 15%, depending on their age and other factors like external temperature. However, new liquefaction units will be much more efficient, for instance the energy consumption of the Snøhvit liquefaction plant started in 2008 is about 6%.
- → **Improving compressor efficiencies for long distance transmission**: new projected pipelines as well as programs on technical upgrading of existing gas transmission facilities will improve the environmental performances of long distance chains. The Gas Industry makes significant investments in such programs: in Russia, annual investments in the renovation of gas compression units until 2030 are evaluated to be more than USD 2 billion [7].
- → **Reducing gas flaring during production on associated fields**: the flaring rate during gas production on associated gas and oil fields generally reaches between 0.1 and 0.5%. However, this percentage may be much higher, for instance in Nigeria.
- → **Reducing leakages along the transport and distribution pipelines**. Continuous renovation of old cast iron distribution mains strongly contribute to this goal.

The results presented here may also be used to identify further actions, including at a regulatory level. Indeed some emissions (SO_X for example) are not due to the natural gas itself but to the use of electrical auxiliaries of the conversion systems. Such distinctions could be made in relevant regulations.

This study allows quantifying LCA results specific to the European context and shows the limitations of using generic European LCA databases for National policies. Since the launching of the Working Group in 2004, the political borders of Europe have been extended to 27 countries and several mergers have taken place in the Gas Industry. Along with these transformations, some progresses have been made from a technological point of view (e.g. diesel-electric engine). An update of this LCA should thus be undertaken in order to keep up with the evolution of both natural gas industry and technologies used along the natural gas chain. Furthermore, this update would be an opportunity to improve the representativeness of the study.

A critical review has been done on this study [8], certifying that the LCA conducted complies with the requirements of the ISO standards 14040 and 14044. In the future, other essential substances will have to be included for a more comprehensive evaluation of the environmental performance of natural gas systems, in order to enlarge the current scope to other environmental impact categories, for example impacts on water resources.

7. REFERENCES

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8. LIST OF TABLES

9. LIST OF FIGURES