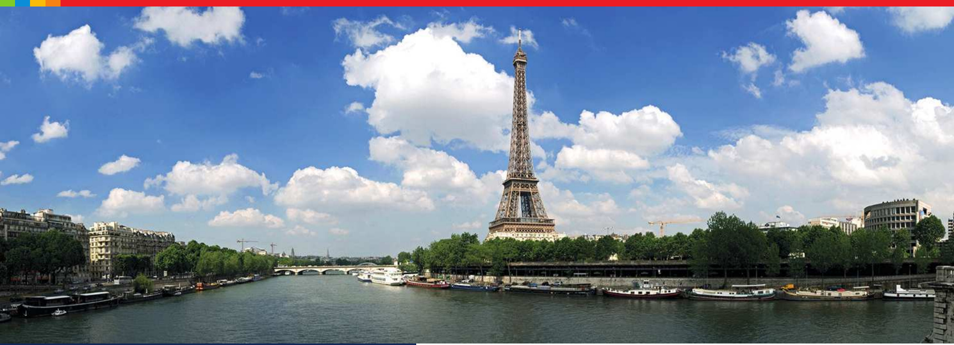
2012-2015 Triennium Work Reports



Opportunities and challenges of LCA applied to the natural gas industry

PROGRAM COMMITTEE A: SUSTAINABILITY

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2012-2015 Triennium Work Report

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Executive Summary:

This report was written by the members of the Study Group on Life Cycle Assessment (LCA) during the 2012-2015 IGU triennium. It describes how can be used by the natural gas industry and details some propositions to improve its use amongst the natural gas companies.

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Introduction

Project background

Following the work done during the 2009-2012 Triennium in the GHG Reduction Technology Guideline, the International Gas Union's (IGU) Program Committee A Sustainability decided in 2012 to launch a specific work on Life Cycle Assessment (LCA) applied to the natural gas chains during the French presidency.

LCA is indeed becoming a reference methodology for the industry in general and for the gas industry in particular, to assess the environmental performances of natural gas chains and natural gas uses.

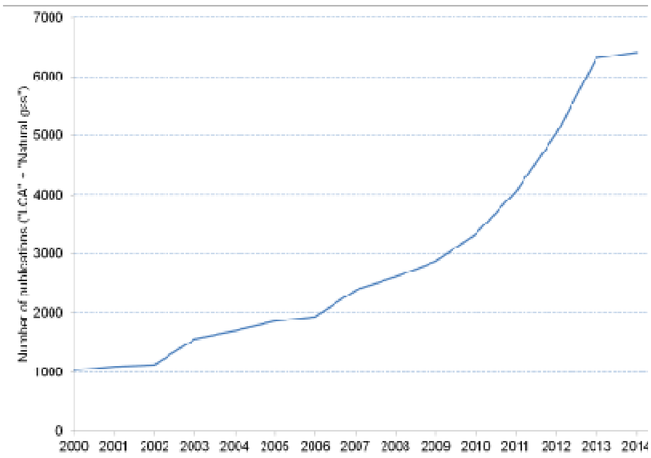

Figure 1 - Number of scientific publications dealing with Life Cycle Assessment and Natural Gas. Based on results obtained from Sciencedirect website with the two keywords "Life Cycle Assessment" and "Natural gas".

The use of LCA has been increasing in the recent period (Figure 1), in particular since the mid-2000', driving by the emerging new technologies (e.g. carbon capture and storage) and new energy pathways (hydrogen, unconventional gases, biogas and biomethane).

This study build on earlier life cycle assessment projects related to natural gas chains:

- The natural gas chain – Toward a global life cycle assessment, 2006 report commissioned by Gasunie for IGU (1),
- Life Cycle Assessment of the European Natural Gas Chain focused on three environmental impact indicators, Final report, 2011, report from the Marcogaz study (2).

It is also strongly linked to the work done in other study groups:

- In Program Committee A Sustainability, with the study groups dedicated to renewable gases, to CCS and to unconventional gas,
- In Program Committee D Liquefied Natural Gas, with the study group dedicated to the LCA of LNG chains.

Some data, references and concepts are common to the three study groups, but the aim and the content of the reports are independent.

Goals of the study: How LCA can be used bas the natural gas industry ?

How LCA is used within gas companies ?

A survey was conducted amongst IGU members during the year 2014, in order to understand if and how Life Cycle Assessment is used by the natural gas industry in practice. Even if the survey doesn't cover the whole gas industry (16 companies have answered), the results can be used to draw the tendencies of the use of LCA within the natural gas sector:

- LCA is clearly identified as a tool for environmental impact assessment (75% of the answers), even if 40% of the companies are not using it;
- Some companies still don't use LCA because they feel that there is too much uncertainty associated to the results although all answering companies find LCA useful or even necessary for the natural gas industry;

- LCA is seen as a relevant tool because it grasps the whole picture for value chain of natural gas and associated environmental impacts (33%) and because it can be used to compare on a relevant basis natural gas with other energy carriers (56%);
- The main use of LCA seems to be environmental communication (58%), followed by benchmarking and requests from the authorities (42% each), orientation of strategic decisions (25%) and finally ecodesign and lobbying (17% each);
- Some companies (44%) claim to have targets to reduce their impacts over years from a LCA perspective;
- Most of the results are published externally (64%) either through a specific reporting (55%) or together with the sustainable development report (36%); specific communication to the authorities represents 18% of the communication mode of LCA results and scientific communication only 9%;
- More than half of the companies claim that they are updating their LCA on an annual basis;
- A few companies claim expertise in LCA (10%) whereas the majority considers itself to understand LCA enough to make a correct interpretation of associated results or even to perform an assessment, but not as experts (70%);
- 30% of the companies who answered have a dedicated internal LCA team, whereas 40% are externalizing their LCAs (the remaining 30% being only using published results).

Some examples of 4 companies are detailed below.

The case of Eni

Eni is involved in R&D activities focused on the optimization of processes related to oil & gas exploration, production, refining, transport and distribution of hydrocarbons and products, renewable sources and environmental protection. The research projects aim to identify breakthrough solutions to be applied in the main business areas of the company with the objective of reducing environmental loads. For this purpose, eni committed a working group to quantify, in terms of environmental impacts through the LCA method, all the benefits of new products and process developed in eni labs. This evaluations are carried out following the specific related standards and through the use of GABI 4 software (PE International) and updated databases. eni is evaluating, at the moment, the impacts of in house patented Ecofing process for the production of a biofuel to be blended to fossil fuel. On this issue, the LCA methodology defines savings in terms of greenhouse gas emissions (GHG) and verifies the sustainability criteria suggested by the RES 2009/28/CE directive about biofuels.

The case of GDF SUEZ

GDF SUEZ applies LCA since the mid-90’s. Applications cover R&D activities, for instance for the assessment and design of new energy pathways such as second generation biomethane. On this issue, LCA helps assessing savings of GHG as compared to the fossil reference defined by the RES 2009/28/CE and also to improve all environmental impact categories by assessing the various scenario (supply chain, processes chains) at an early stage of development. LCA is also used within GDF SUEZ to promote the environmental performances of natural gas, for example in the case of LCA applied to building. More recently, LCA has been applied to organizations, i.e. to all the activities of a given subsidiary of GDF SUEZ, in order to better understand the environmental impacts and to quantify the potential benefits from action plans at the company level. GDF SUEZ uses the Simapro software (Pré Consultant) and internationally recognized databases such as Ecoinvent. As water footprinting has recently gained importance, in parallel to climate change, GDF SUEZ is also using the Water Database (Quantis) and the Quantis Suite software.

The case of Osaka Gas

There are two main objectives for conducting Life Cycle CO_2 analysis in Japan:
• as a basis for the identification of suitable energy supply/demand balance of fossil fuels among natural gas, coal, crude oil and LPG.
• as a measure of potential GHG emission reduction in each value-chain process in each business.

The case of KOGAS

KOGAS has applied LCA to acquiring the label of EDP (environmental declaration products) managed by the ministry of environment (ME) in Korea in order that natural gas is considered as an ecofriendly fuel. KOGAS has utilized Total software and LCI D/B which have been developed by ME and also GABI LCI D/B in specific chain of natural gas industry because of no exploration, production activities in Korea. R&D activities of LCA have focused on transportation, storage, regasification, transmission and utilization. However, the management of KOGAS has decided to acquire Carbon Emission Certificate which is low carbon green production/consumption service system managed by ME instead of getting the label of EDP because of the complexity of LCA and question of EDP's necessity and in part of natural gas vehicle, well to wheel analysis comparing other fuel is proceeding and it has difficulties to get and verify the LCI D/B of exploration and production. Therefore, the results of this study group will be a very useful to solve these difficulties in well to wheel LCA.

Outline of this report

A general overview of the LCA methodology and its potential uses in the natural gas industry is given in chapter 1. Chapter 2 details some practical applications of LCA in the natural gas sector. A focus is included on the expected new technologies or new chains, that may modify the environmental performances of natural gas, such as carbon capture and storage (CCS), non conventional gases or renewable gases. Finally, chapter 3 discusses the limits and improvements of LCA in order that is becomes widely used towards a more sustainable natural gas chain in the future.

Chapter 1-What is LCA, how can it be used in the NG industry ?

Why using LCA in the NG 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) (3). Moreover, there are increasing expectations from all stakeholders, including the civil society, investors, suppliers, final customers and competitors towards transparent information on environmental impacts of products and services, in order to anticipate potential risks on the environment. As a utility, natural gas is concerned by these expectations. In this context, IGU PGC-A has set up a working group on LCA for the 2012-2015 triennium, aiming at explaining how LCA may help the natural gas industry:

- meeting stakeholders expectations towards complete information on the environmental impact of the natural gas chains,
- promoting the environmental performance of natural gas,
- advocating for the development of natural gas as a foundation fuel for Sustainable Development.

What is LCA ?

Life Cycle Assessment (LCA) is a methodology developed for the evaluation of environmental impacts associated to a product, a service, a process or even an organization. It is a standardized approach (4) and (5), recognized by both the academic and the industry sectors as an efficient tool to support decision making and also to evaluate the global environmental performances of products and services, for instance for products benchmarking.

All the stages in the lifetime of an object (extraction, processing, recycling, etc.) and all types of impacts (greenhouse gas emissions, acidification, resources depletion, toxicity, ionizing radiation, impacts on water resources, etc.) and damages on ecosystems, human health and resources are taken into consideration through an in-depth analysis of incoming and outgoing flows. It is thus a multi-criteria environmental evaluation methodology of which Global Warming Potential is only a part. As an example, the steps included in the case of LCA applied to 1 MJ of natural gas distributed to the final customer is given Figure 2. All those steps have to be included in the LCA in order to have a complete view of the environmental impacts associated to natural gas.

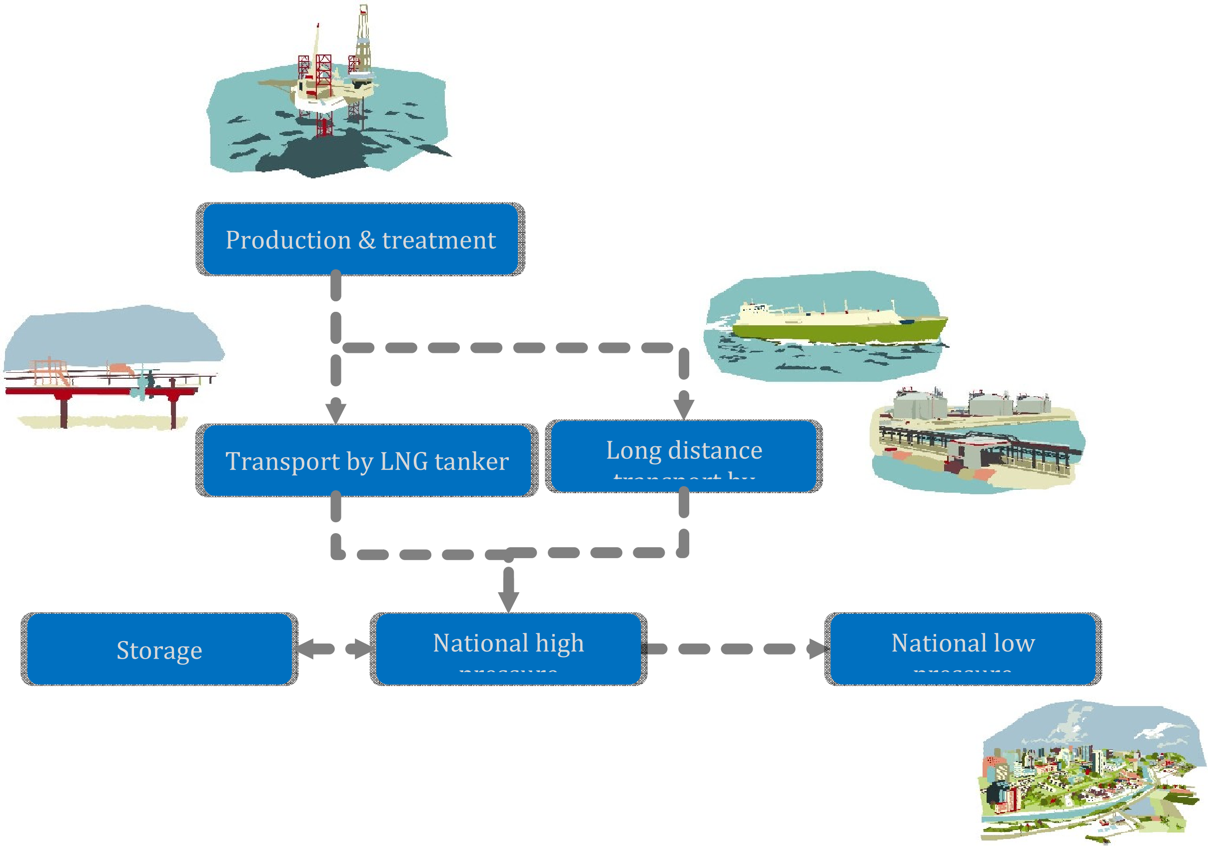

Figure 2 - The life cycle of 1 MJ of natural gas distributed to the final customer (source: GDF SUEZ).

The assessment is divided into 4 main steps, as described Figure 3: once the scope of the study is set, environmental impacts are calculated based on the inventory of material, energy and emissions to and from the system. It should be noted that LCA is an evolving methodology: improvements are constantly available, for instance in terms of impacts characterization. Recently methods have been developed in order to better account for water footprint in LCA.

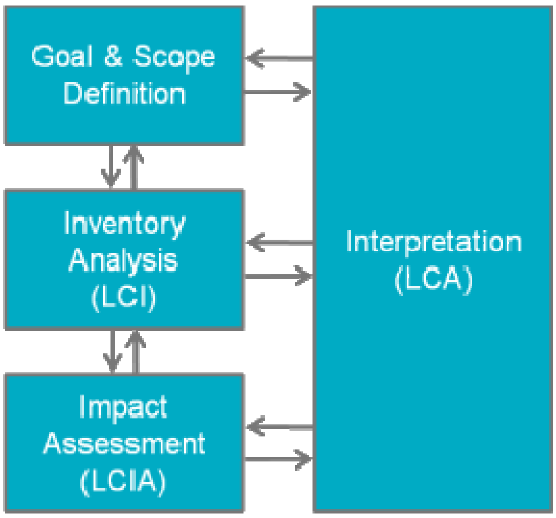

Figure 3 - The 4 steps of a LCA, as described by ISO 14040.

LCA applied to natural gas : challenges

In the industry, LCA may be used for several purposes (Figure 4).

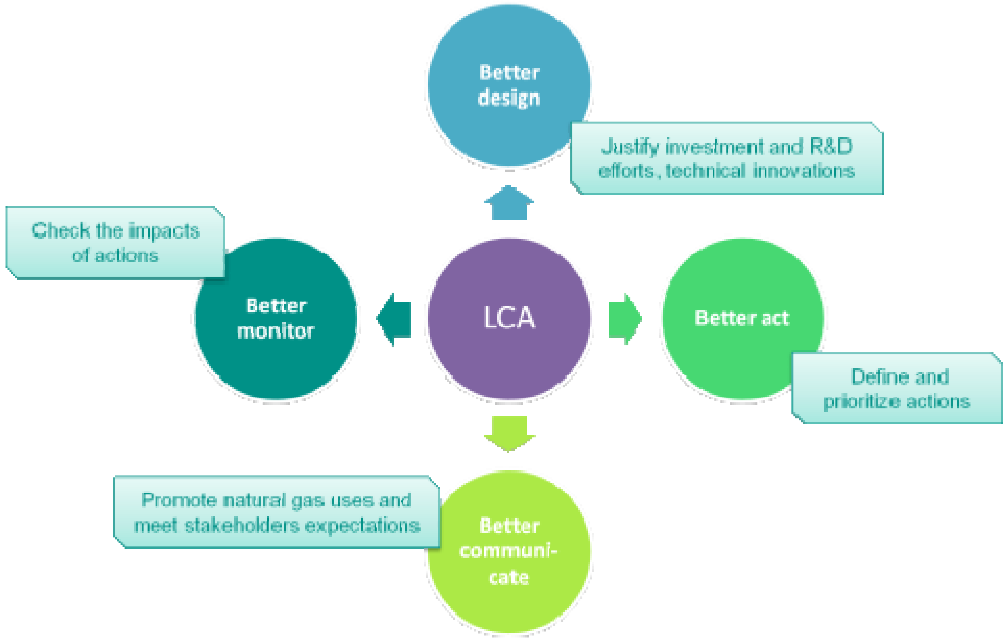

Figure 4 - The added value of LCA.

Applied to the natural gas chains, LCA can become an efficient tool to promote its environmental performances and to improve it. Examples detail below some concrete applications.

An example is the LCA performed on the whole European natural gas chain by the LCA working group of Eurogas–Marcogaz Joint Group on Health, Safety & Environment (6).
Results from this study are shown Figure 5 and Figure 6.

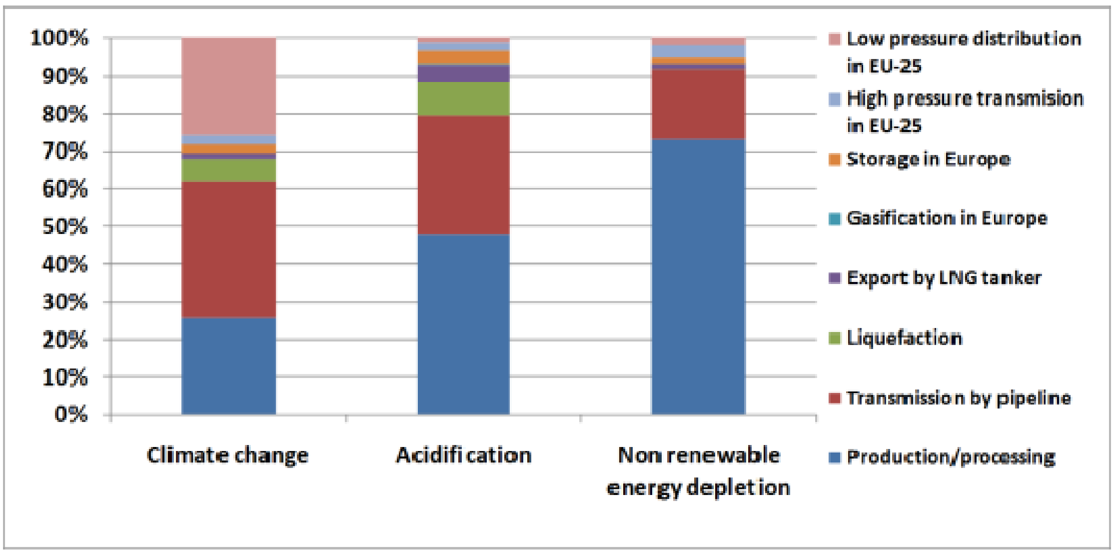

Figure 5 - Contributions of each step of the upstream natural gas chain to 3 environmental impacts (7).

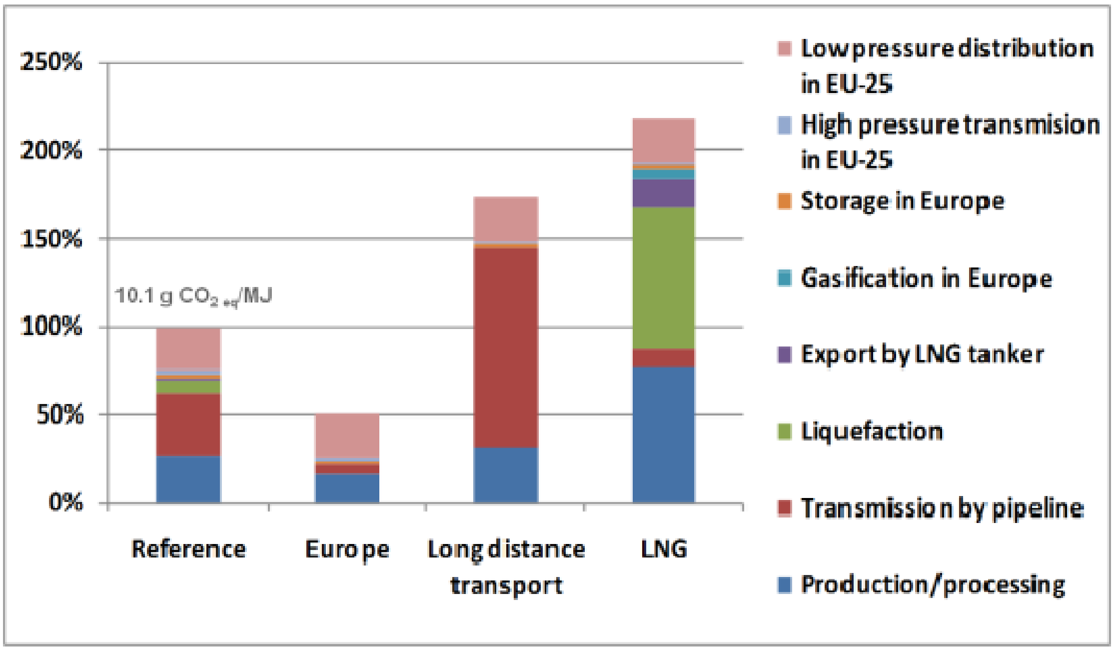

Figure 6 - Comparison of the repartition of GHG emissions along the upstream chains (7).

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. In this case, LCA has been used to quantify the impacts associated to each step and the extent of impact reduction that can be expected from each action. This application of LCA can also be used to benchmark the environmental efficiency of the various actions.

Chapter 2 – Overview of the potential uses of LCA in the natural gas industry based on examples from the literature

This chapter is not meant to be an exhaustive literature review of environmental impacts of the various natural gas chains assessed with LCA. The objective is more to illustrate how LCA is implemented in practice, what kind of results it can bring to the natural gas industry and for which purposes.

This review is only based on published assessments. It is obvious that other applications of LCA are done within companies, that are not published, in particular with the objective of supporting internal decisions.

Four examples are presented, that fit with the scope of the Program Committee of the IGU on Sustainability:

- LCA applied to unconventional natural gas resources,
- LCA applied to carbon capture and storage (CCS) technologies,
- LCA applied to renewable gases,
- And as a starter, LCA applied to conventional energy pathways.

LCA applied to conventional energy pathways

Main impacts and impacting steps of the natural gas chain

Amongst the available studies presenting LCA results applied to conventional natural gas chains, most are aiming at benchmarking natural gas with other energy pathways, such as electricity produced from coal or fuel oil. The vast majority of those studies focus on greenhouse gases emissions, assessed on the whole life cycle of the energy pathway.

Figure 7 shows a summary of the impacts studied in the literature. As already said, climate change is widely studied in comparison of other types of impacts, because of the strong focus set on this issue. Acidification and total primary energy consumption are the second impacts assessed with LCA for natural gas, because the flows contributing to those impacts are well documented in the natural gas industry (energy consumptions and acidifying emissions – NO_X, SO_X mainly).

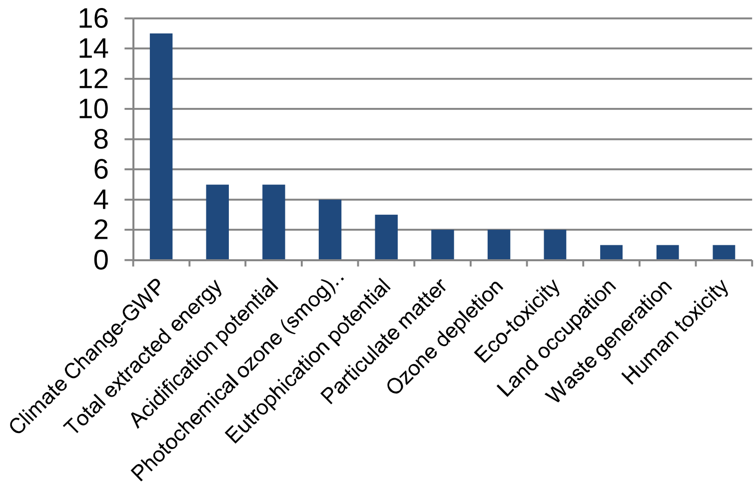

Figure 7- Summary of impacts categories studied in the literature (in number of studies)

The vast majority of published LCAs compares GHG emissions from natural gas supply chains with other types of fossil fuel supply chains :

- o In all the studies comparing gas chain with coal chains, GHG emissions from gas chains are lower and represent 50 to 75% percent of the impacts of coal chains on climate change.

- This is also the case for other impact categories, such as acidification.
- This is mainly explained by the lower emissions generated by the combustion of natural gas in comparison of oil or coal: natural gas combustion emits less particulate matter, sulphur dioxide and nitrogen oxides than coal or oil [9].

If the whole life cycle is taken into account, the use phase of the natural gas is the main impacting step in terms of climate change (Figure 8, Figure 9 and Figure 10), with 80 to 90% of the impact.
Figure 8 shows GHG emissions calculated from the supply chain and the entire gas chain, with and without the utilization step.

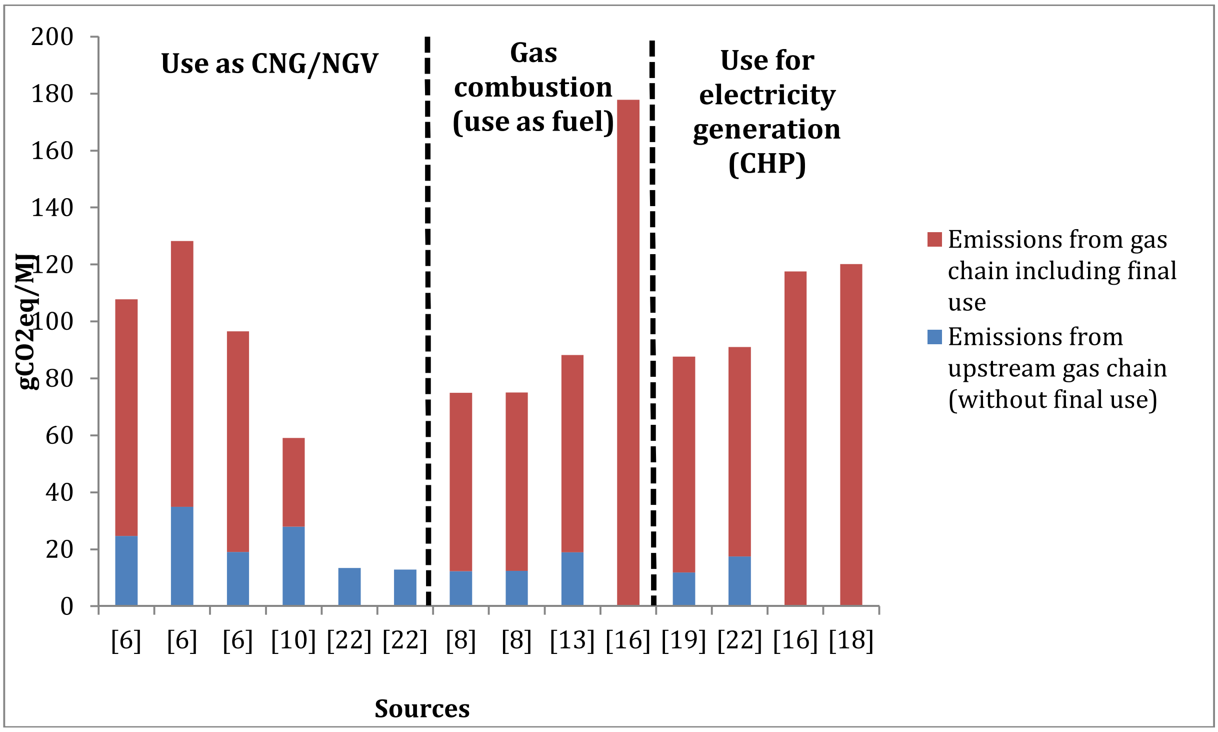

Figure 8 – Normalized comparison of GHG emissions evaluated in the literature (upstream : supply chain from production to low pressure distribution of natural gas)

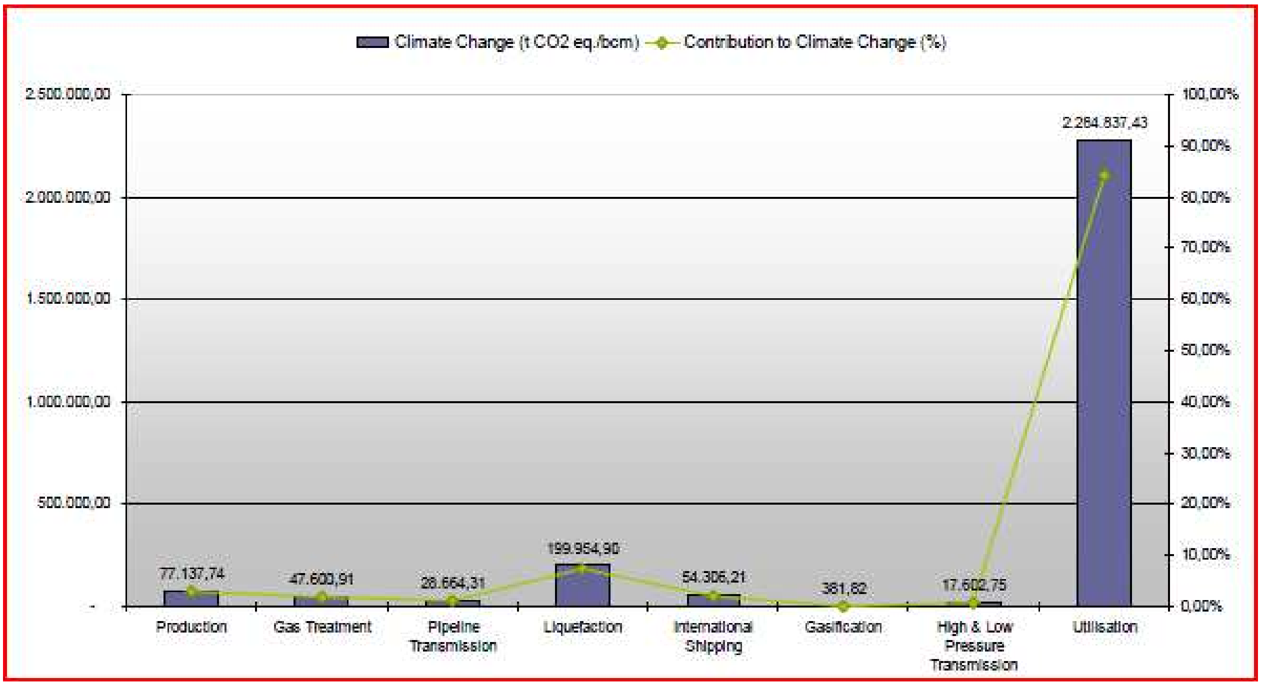

Figure 9 – Contribution to Global Warming (referenced to bcm) [19]

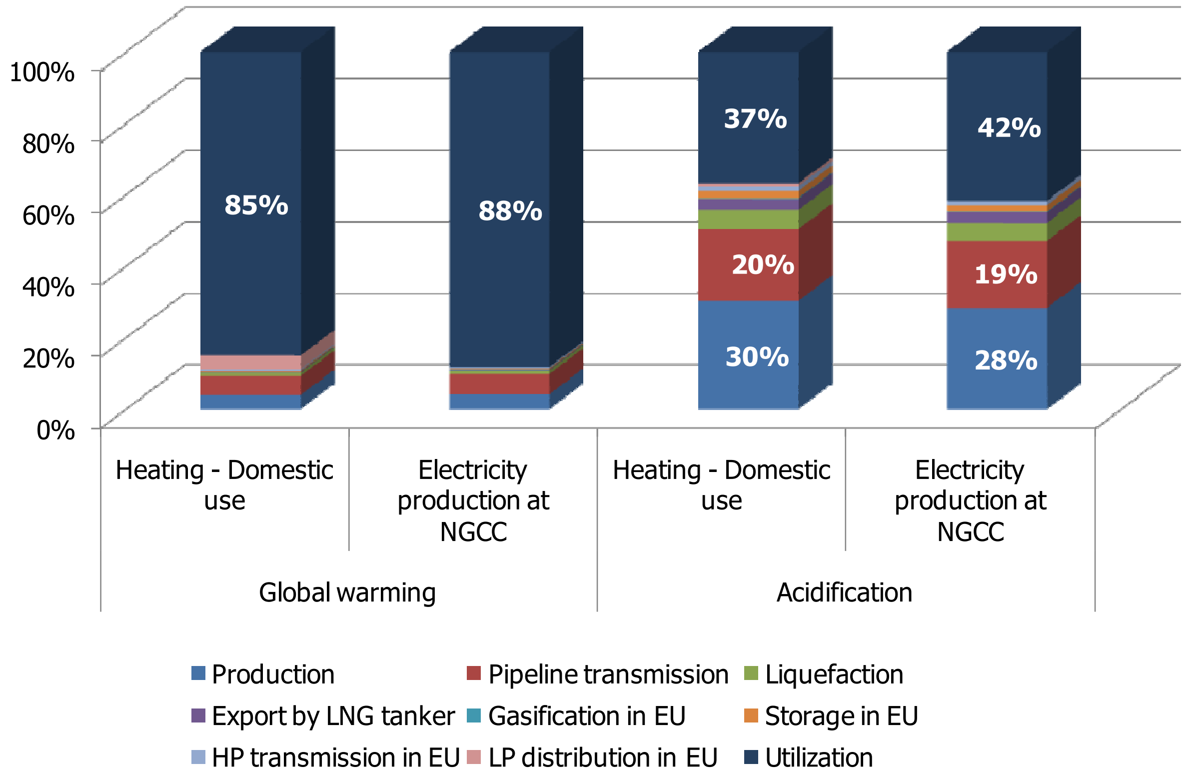

Figure 10 – Main results from Eurogas-Marcogaz study (2)

Considering GHG emissions from the natural gas supply chain (without the use phase), the most contributing steps may differ from one type of supply to the other. The two main contributors to climate change (except from natural gas final use) are the liquefaction step in the case of NG supply and long distance transmission by pipeline. However, it should be mentioned that the use of electro-compressors has allowed a significant reduction of direct atmospheric emissions for the transmission step. Transmission presents thus less impact on Climate Change than Production & Processing activities for some supply chains, e.g. natural gas produced in Europe (Figure 6).

Another comparison of GHG emissions from a LNG supply chain has been made assuming a Qatari LNG supply chain (Figure 11): the results are also pointing out the liquefaction step as a major contributor to climate change.

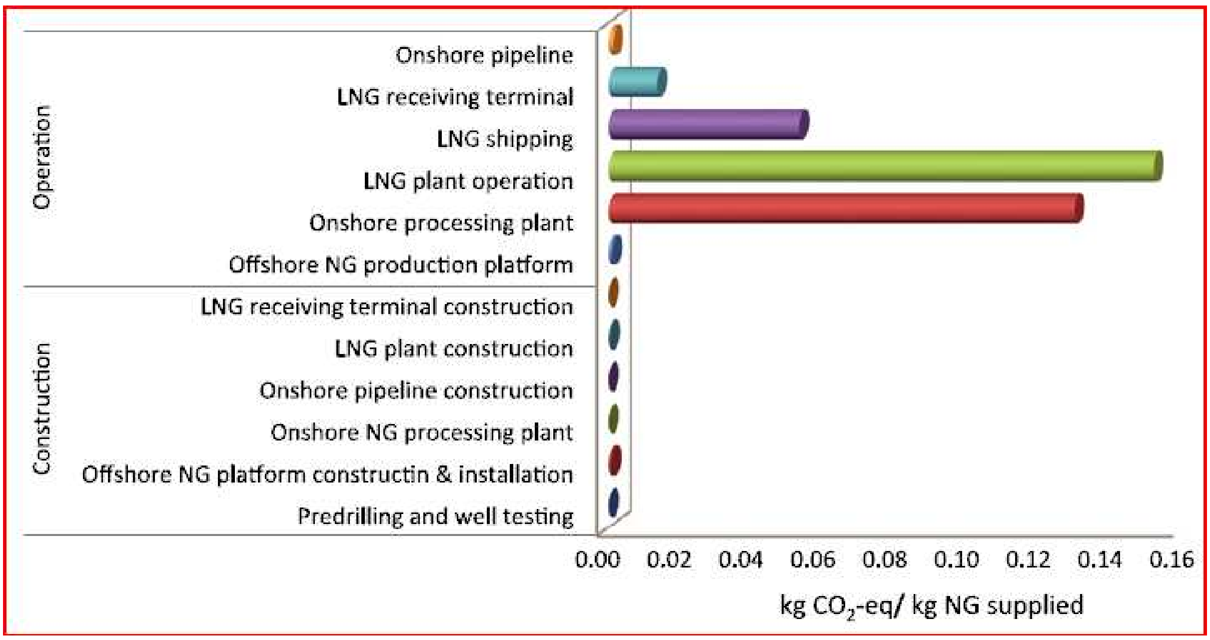

Figure 11 - GHG emissions per kg NG supplied from North Field (Qatar) to South Hook (UK) (8)

It is of course relevant to tackle the issue of climate change, but there is a lack of studies looking at other impact categories that may also be relevant, such as acidification potential and fossil resources depletion.

Indeed, more and more LCA are conducted in the gas industry: some studies have begun to look at other possible impacts and to demonstrate that technologies can significantly improve an impact (GHG) but not necessarily all. As we begin to know about the impacts of the gas chains on climate change, it would be relevant that future studies consider other impact categories, as the ISO 14040 standard advocates. Raising issues such as water footprint or local pollution are also important to be taken into account by the natural gas industry.

As an example, when considering acidification (Figure 12 and Figure 10), the utilization step still represents the greatest impact, but to a lower extent as compared to climate change. It should be noted that there is a potential for reduction of SOx emissions due to new regulations (first in the Baltic sea, then North sea, and Mediterranean sea under discussion)

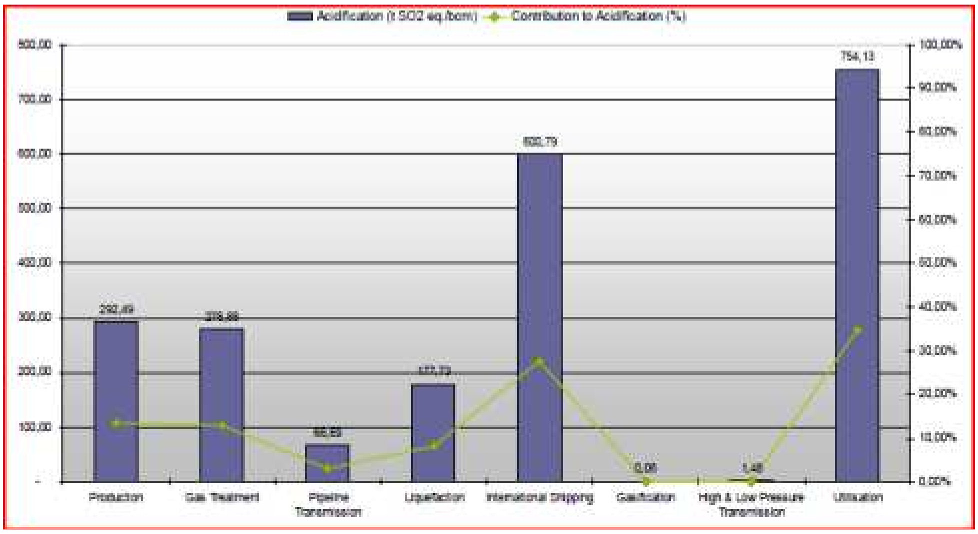

Figure 12 – Contribution to acidification (referenced to bcm) [19]. Low pressure = distribution; High pressure = national transmission

In the case of air toxicity, the impact of international shipping is the most important (Figure 13).

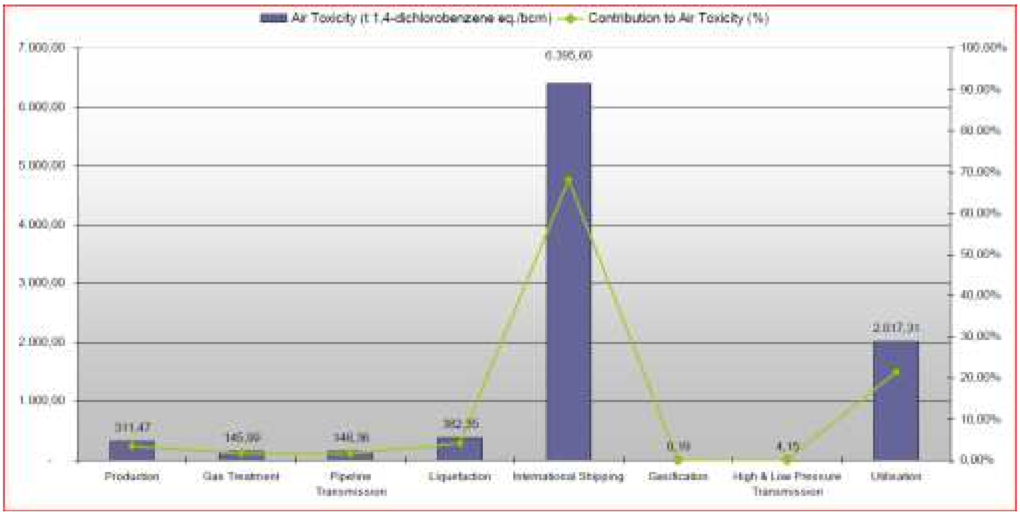

Figure 13 – Contribution to air toxicity (referenced to bcm) [19]

This example clearly illustrates the interest of a multicriteria approach: the next step is to have robust decision making processes, that can take into account several environmental criteria. This is a field for further improvement of LCA methodologies, as there is no clear consensus at the time on how to take all those criteria into account.

Main sensitive parameters of the gas chain in the literature

The literature review enlighten the main parameters that are driving the environmental assessment of the conventional natural gas supply chains.
Considering only the natural gas supply chain (excluding the final use of the gas), the main sensitive parameters are (2):

- Methane emissions rate on the long distance export pipeline system during transportation,
- Global auto consumption rate during sweetening process,
- Compressor efficiencies and efficiency of the liquefaction step.

Depending on the supply chain, these parameters may vary significantly, thus having an influence on the final impact assessment. For example, Table 1 presents the main sensitive parameters of gas supply chain to Asia.

Key parameters	Min	Determined	Max
Flaring during recovery (g CO_2/GJ process)	447	514	581
CO2 Venting during processing (gCO_2/GJ process)	935	935	1814
Liquefaction efficiency (%)	92,64	92,51	92,38
LNG recovery rate in foreign country (%)	90	80	75
LNG recovery rate in LNG carrier (%)	95	90	85
CH4 leakage in Korea (g CH4/GJ process)	30,71	45,37	82,48

Table 1 – Main parameters for an Asian gas supply chain (9)

Indeed, process efficiencies, among others, are used widely to determine GHG emissions, as shown from the main parameters assessed by (10).

Moreover, the value of those parameters can vary greatly depending on the methodology used to assess them. At the European scale, Marcogaz has developed a dedicated methodology to calculate atmospheric emissions from the gas industry, but there is no consensus worldwide. Contributors thus collect data with different scopes. This highlights the difficulty of data collection and standardization worldwide in the gas industry.

This is particularly true for methane emissions, which are proven to be a very sensitive parameter in the life cycle assessment of natural gas chains.

Focus on methane (CH_4) emissions

As methane is the main compound of natural gas, it represents the main source of GHG emissions when natural gas is emitted to the atmosphere. The widening of the gas industry knowledge about this compound and the way to minimize its emissions is thus a consistent and effective manner to minimize the impacts of gas chains on climate change.

What is Methane (CH_4)?

Methane (CH_4) is one of the four anthropogenic and long-lived greenhouse gases (GHGs), including carbon dioxide (CO_2), nitrous oxide (N_2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine), and its global warming effect is second to CO_2. According to the IPCC AR5, the atmospheric concentration of CH_4 has increased since 1750 due to human activity to the level of 1,803 ppb in 2011, exceeding the pre-industrial levels by approximately 150%.

The equivalent of CO_2 emissions is obtained by multiplying the emission of CH_4 by its Global Warming Potential (GWP) for the given time horizon. The GWP for CH_4 has been under research and a report on its recent result was published in 2013 by IPCC. According to the report, both GWP for 20 years and GWP for 100 years increased from the data in the IPCC AR4 published in 2007, which were 72 and 25, respectively. The appropriate time horizon should be set for calculating the

CO_2-equivalent of CH_4 in a given background and context, where 100 years has been commonly used. Examples are found in the UNFCCC reports and Kyoto Protocol, 1997.

Time Horizon	20 Years	100 Years
GWP, without inclusion of climate-carbon feedbacks	84	28
GWP, with inclusion of climate-carbon feedbacks	86	34

Table 2 – GWP for CH4, based on (8)

Where are CH_4 emitted from in the gas industry and how to minimize CH_4 emission?

In the gas value chain, as shown in Figure 14, CH_4 is emitted by venting at the production site, leaking during transportation and distribution, releasing during maintenance and measurement at governors, etc. There are several methods for measuring gas leakage in pipeline networks such as measuring the pressure fall in leaked pipeline, and so on, though it is very difficult to measure CH_4 emission amount precisely since it is very tiny.

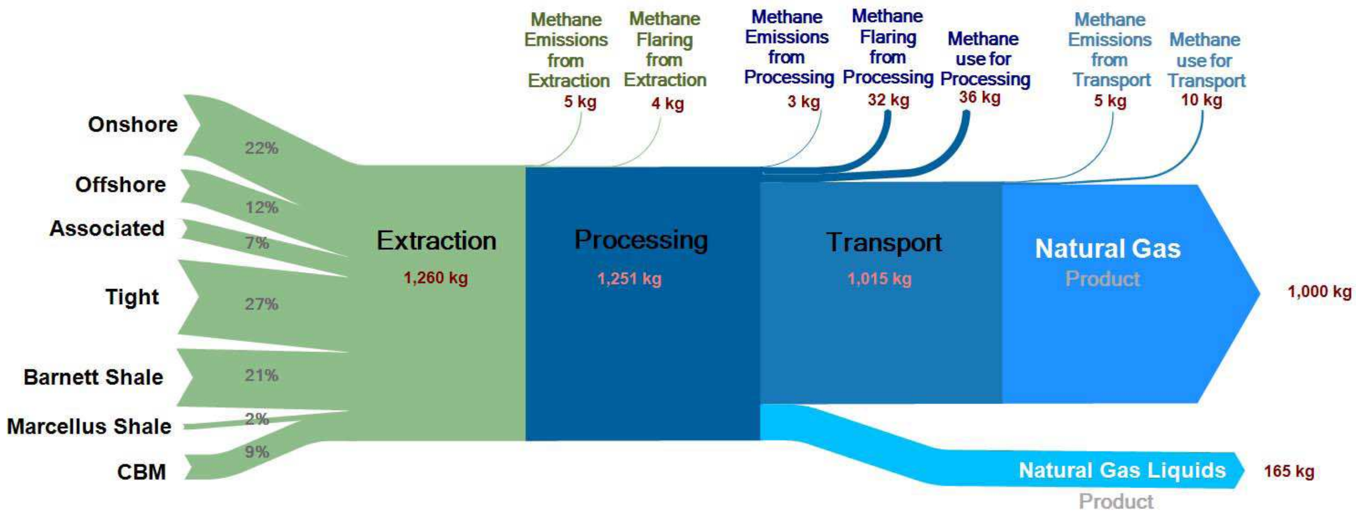

Figure 14 – Methane emissions Sankey diagram of a simplified natural gas chain in the U.S.A[1]. (12)

To minimize the amount of CH_4 emission, several practices has been implemented in the each emission point throughout a gas value chain as shown below.

(1) Production: Flaring instead of venting.
(2) Natural gas transport by pipelines: Maintenance of leaked pipelines, valves and other equipment, reduction of compressor emission, and so on.
(3) Distribution: Maintenance and replacement of old pipeline networks, pressure management and so on.

As the parameter of methane emission is a key issue in the environmental assessment of natural gas, one of the recommendation is that the gas industry should work on an harmonized methodology to evaluate the methane emissions : at the world scale, this could be done or at least initiated within IGU.

[1] Natural gas is not processed during transport : after processing, the gas is not raw gas any more, but has reached « natural gas » quality.

Impacts related to technological improvements in the past

Recent technical evolution made it possible to shrink further the environmental footprint of the gas industry, by reducing the volumes, surfaces or time needed for operations, by limiting the emissions of particularly methane, or by increasing the efficiency of the operation.

Exploration step

The environmental impacts of exploration has been decreased by new techniques allowing to lower the number of exploration drills needed, by new drilling techniques and materials giving fast feedback or using less materials and needing less drilling mud:

- A lower number of exploration drills can be achieved by new techniques in the field of exploration (e.g. use of vibrational sources instead of explosives, use of 3D and even time path inclusive4D seismic imaging);
- The use of a long flexible coiled pipe strings instead of jointed drill pipe and the use of coiled tubing;
- The slimhole drilling using a drill bit less than six inches in diameter instead of the mainly 12.25 inches leads to a smaller footprint,
- Measurement-while-drilling systems, giving immediate data on the exact nature of the underground drilled, make it possible to collect data during the drilling and allowing fast reactions. This improves drilling efficiency and accuracy in the drilling process.

Production step

The footprint of natural gas production has been decreased by better maintenance and higher efficiency of material (greater energy efficiency, less emissions of CO_2 and methane) and by newer fracturing methodology (less water, utilization of CO_2). The capture of casing head gas and the improvement of the glycol dehydrating circuit are other ways to decrease the footprint.

- Fracturing using a mixture of exclusively liquid CO_2 and sand leads to an extended production of the wells,
- Higher efficiency of compressors,
- Better maintenance of pipes and valves, reducing emissions
- Use of compressors to capture the casing head gas
- Improvements of the glycol circuit (reroute glycol skimmer gas in dehydrators; pipe glycol dehydrator to vapor recovery unit; replace glycol dehydration units with methanol injection; optimize glycol circulation and install flash tank separators in glycol dehydrators; replacing gas-assisted glycol pumps with electric pumps; replacing glycol dehydrators with desiccant dehydrators)

Transport of natural gas

The footprint has been decreased by lowering the emissions of methane in the different elements of the transport activity: pipes, compressor stations, venting and flaring, valves :

- Reduction of emissions in case of maintenance of pipelines or extension of grid (lower pressure, transfer of gas to distribution grid, mobile re-compressor unit to other transport pipe, external repair techniques)
- Reduction of emissions of compressor stations

Examples of measures include: no depressurizing after unit shut down, electrical start-up, dry gas seals and use of a gas recovery equipment with re-compressor, use of low emitting pneumatic actuators, use of isolation valves upstream and downstream of the gas cooler unit in compressor stations and their location as close as possible to the compressor units.

Measures to reduce emissions from compressors become more important since the liberalization of the European gas market leads to more frequent and un-programmed start-up and shut downs in compressor systems and are interfering with classic maintenance schedules.

Very low imposed NOx emission level values can lead to the replacement of natural gas driven compressor by power driven compressors, even if this means that safety of supply becomes dependent of power supply. The installment of electric starter motors or the replacement of gas starts with air or nitrogen, are other techniques used by the industry to decrease emissions, together with the reduction of methane emissions from compressor rod packing systems, and possibly the replacing of wet seals with dry seals in centrifugal compressors.

- Reduction of venting and flaring

Recovery equipment with recompressing, flaring instead of venting, reduced vent/flare purge gas streams, the injection of blowdown gas into the low pressure grid or in the fuel gas system; the reduction of emissions when the compressors are taken off-line, the recovery of gas from pipeline pigging, and the use of pipeline pump-down techniques lowering the pressure before maintenance

- Use of air / electric actuated valves on the grid, in metering stations instead of gas driven actuators (however, making the gas grid dependent of the power grid).
- The improvement of maintenance techniques leads also to lower emissions: the testing and possibly repair of pressure safety valves, the use of pipeline pump-down techniques lowering the gas pressure before maintenance operations, the use of hot tapping
- Campaigns of monitoring of emissions by patrolling by foot, car or even helicopter

Storage step

The footprint has been decreased by lowering the emissions of methane in the different elements of the transport activity: pipes, compressor stations, venting and flaring

- Reduction of emissions of compressor stations

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- Reduction of venting and flaring, and the use of flaring instead of venting
- Recovery equipment of gas to be vented/flared, with recompressing,
- Reduced vent/flare purge gas streams

Liquefaction of natural gas

The cooling process was made more efficient, using less energy and emitting less CO_2

- Evolution in design of the plant (localisation of the different parts of the plant in order to obtain best heat exchange taking into account the main wind direction),
- Use of more than one coolant and of more than one cooling step,
- Capacity and lay-out of the heat exchangers,
- CHP compressors producing also electrical power

Transport of LNG

The footprint was lowered by use of recompression of the boil-off: less emissions of methane or CO_2 and less other emissions (NO_X, SO_2, particulate)

- Recompressing of boil-off or use of boil-off in ships engines.

Storage of LNG

The footprint was lowered by use of recompression of the boil-off: less emissions of methane or CO_2 and less other emissions (NO_X, SO_2, particulates).

- Recompressing of boil-off or use of boil-off in the plant’s engines.

Regasification of LNG

The footprint was lowerd by less emissions of CO_2 and less energy consumption; studying the alternatives of a planned LNG-chain with double liquefaction made it also possible to shrink the emissions

- Use of (sea)water for gasification instead of burners,
- Use of CHP for gasification in case of burners,
- Avoid regasification/reliquefaction by transport of LNG by barges/trucks in specific cases.

Underground storage

- Measures to reduce emissions from compressors to the storage become more important since the liberalization leads to more frequent injections and deliveries from storages. Examples of

measures are: no depressurizing after unit shut down, electrical start-up, dry gas seals and use of a gas recovery equipment with recompressor, use of low emitting pneumatic actuators, use of isolation valves upstream and downstream of the gas cooler unit in compressor stations and their location as close as possible to the compressor units. The installment of electric starter motors or the replacement of gas starts with air or nitrogen, are other techniques used by the industry to decrease emissions, together with the reduction of methane emissions from compressor rod packing systems, and possibly the replacing of wet seals with dry seals in centrifugal compressors.
- Measures regarding the glycol circuit during production can possibly also be used in case of wet underground storage.

Distribution

- Repair (without replacement and resulting complementary emissions, f.i. composite wrapping) or relining (insertion of flexible liner) of old pipes,
- Pressure management in order to lower the pressure as much as possible,
- Campaigns of emission monitoring by vans
- Replacement of old distribution grid (particularly old grey cast iron networks)
- Hot tapping for connections to pipelines in service, avoiding venting, flaring or recompression

Appliances (power/heating/CNG)

- Trigeneration
- CHP; microCHP
- Direct use of the heat and burned gases

Recovered gas

- Injection of biomethane and of syngas
- Power to gas

LCA applied to new energy pathways

Conventional vs. Non conventional natural gas

In the recent period, more and more studies have been published that use LCA to assess the potential environmental impacts of shale gas production, as compared to other energy sources like conventional natural gas and coal. The vast majority of existing assessments focuses on greenhouse gases emissions, but there are also assessments available for other impact categories, such as water depletion or even a full LCA.

The main objective of most of the available studies is to benchmark shale gas with other energy carriers (conventional gas, coal…), either directly by unit of energy produced (MJ of energy) or as a source for electricity production (in that case the assessment is expressed by kWh of electricity generated). Only a few study are looking at other geographical contexts than USA. Four studies are however available on shale gas environmental impacts in the UK and Scotland : (9), (10), (11), (12).

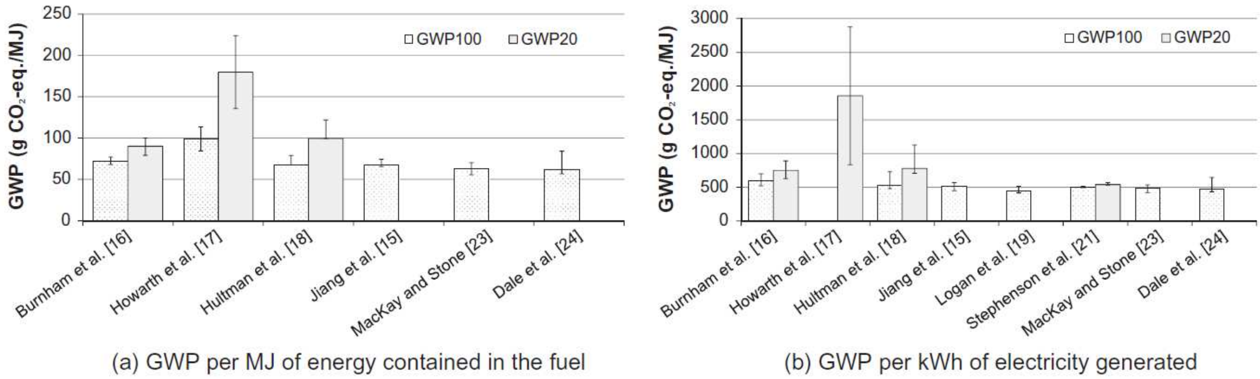

Figure 15 - Global warming potential estimates for shale gas expressed (a) per unit of energy contained in the fuel and (b) per unit of electricity generated in a gas power plant. (Where available, estimates are given for both 100- and 20-year timeframes. Howarth et al. (17) and MacKay and Stone (15) do not give a central estimate, therefore the bar height shown is an average of their lowest and highest results.)

As already said, almost all studies are dealing with greenhouse gases emissions assessment (Figure 16). Only the work of Jiang et al., specific to Marcellus shale formation provides a detailed study on water consumption and wastewater generation impacts (13). The most comprehensive study, in terms of impact categories assessed, is the work of Stamford & Azapagic, who are proposing a full LCA of shale gas in the UK, as compared to other electricity generation technologies (conventional gas power plants, coal power plants, nuclear power plants, solar photovoltaic and offshore wind).

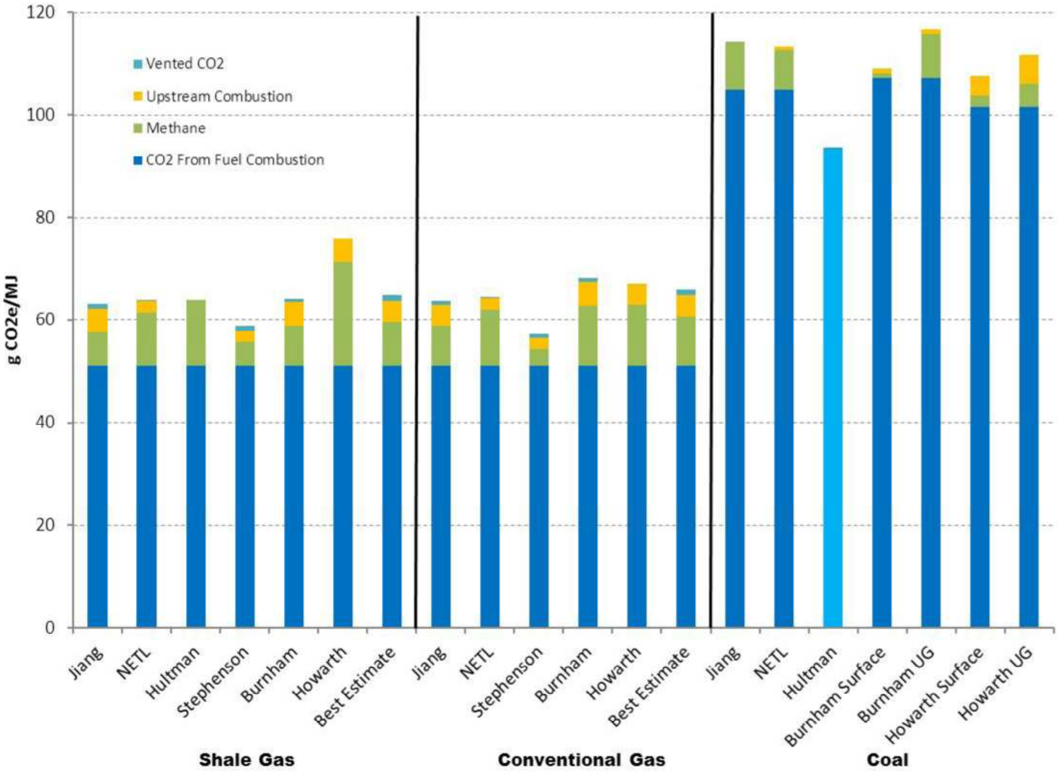

Figure 16 - Natural Gas and Coal LCA Comparison (19) - extracted from a Canadian study from Fulton et al. comparing GHG emissions calculated for North-American supply chains.

Applying LCA to shale gas production has 3 main interests, as illustrated by the various studies identified:

1. To benchmark shale gas, a new energy pathway, with other energy carriers, in order to assess its relevance in terms of environmental aspects; in that sense a multicriteria assessment, such as the one proposed by Stamford & Azapagic, is the most relevant as it gives a wider view.
2. To identify the most impacting steps and parameters for each environmental impact categories, in order to try and improve the technologies and practices or even regulation so that environmental impacts are lowered.

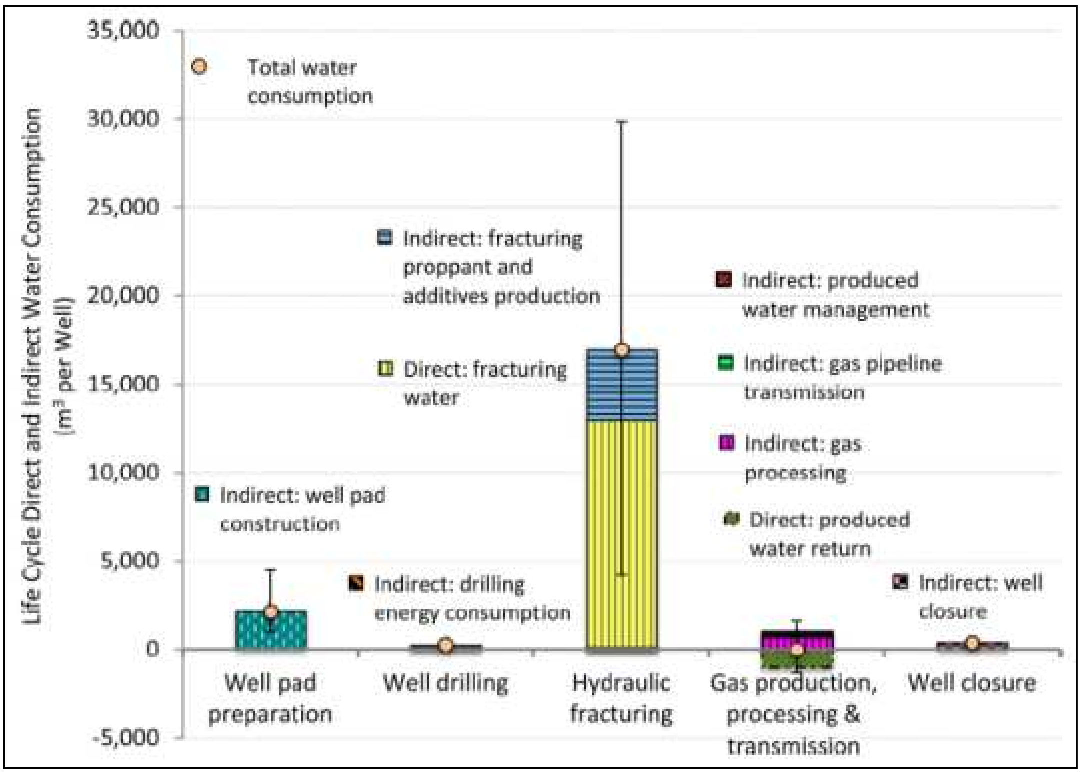

Figure 17 : Estimated life cycle direct and indirect water consumption for a Marcellus shale gas well (from (18))

CCS

Life Cycle Assessment has been applied since several years to carbon capture and storage technologies. This methodology was mainly used to:

1. -quantify the potential GHG emissions reduction, depending on the CCS technology,
2. -identify the potential trade-offs between environmental impact categories.

The results of published LCA show GHG emissions reductions from 63 to 87% per unit of electricity produced, depending on the CCS and electricity generation technologies considered. Although more CO_2 can be captured at the power plant, the GHG emission reduction is lowered because of emissions related to additional operations such as additional fuel supply, use of chemicals (and regeneration in some cases such as absorption using monoethanolamine-MEA) and transport and storage of CO_2. As presented by (20), the main CO_2 capture technologies are post and pre-conversion capture and oxy-fuel combustion.

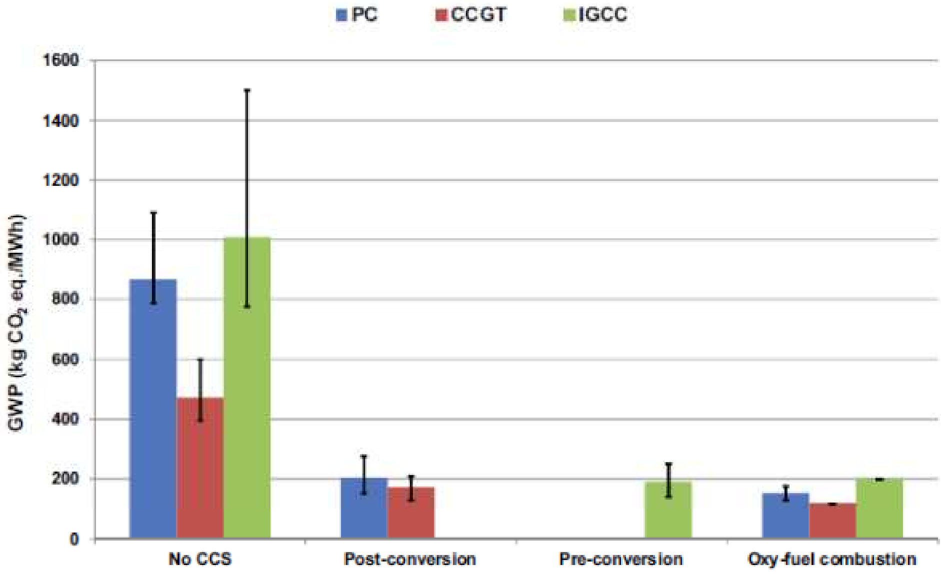

Figure 18 - Comparison of GWP for electricity production with or without CCS (20)

On the other hand, all studies show a higher primary energy consumption and depletion of resources when CCS is implemented. This is directly linked to the lower energy efficiency at the power plant level and to additional material consumptions (e.g. chemicals). This is also linked – to a lower extent – to additional infrastructures needed for CO_2 transport and storage.

Results related to impact categories other than climate change vary among studies, but pre- or post-combustion CO_2 capture generally imply higher environmental impact as compared to a situation without CCS. This is mainly due to:

- higher fuel consumption by the power plant, resulting in higher impacts from fuel extraction and supply
- consumption of additional chemicals, such as MEA,
- or additional emissions, such as ammonia released during the absorption of CO_2 in MEA (14).

Applying LCA to CCS is thus useful to identify the transfer of impacts from power plants to other activities upstream or downstream, or from one type of impact to another.

Renewable gases

The production and use of biomethane is mainly driven by two objectives (15):

1. -the reduction of impacts on climate change,
2. -the depletion of fossil resources.

There are several different routes for the production of biogas and biomethane, with different levels of maturity (Figure 19). Thus, many LCA have been published on biomethane, focusing on the various production and use pathways, with different objectives.

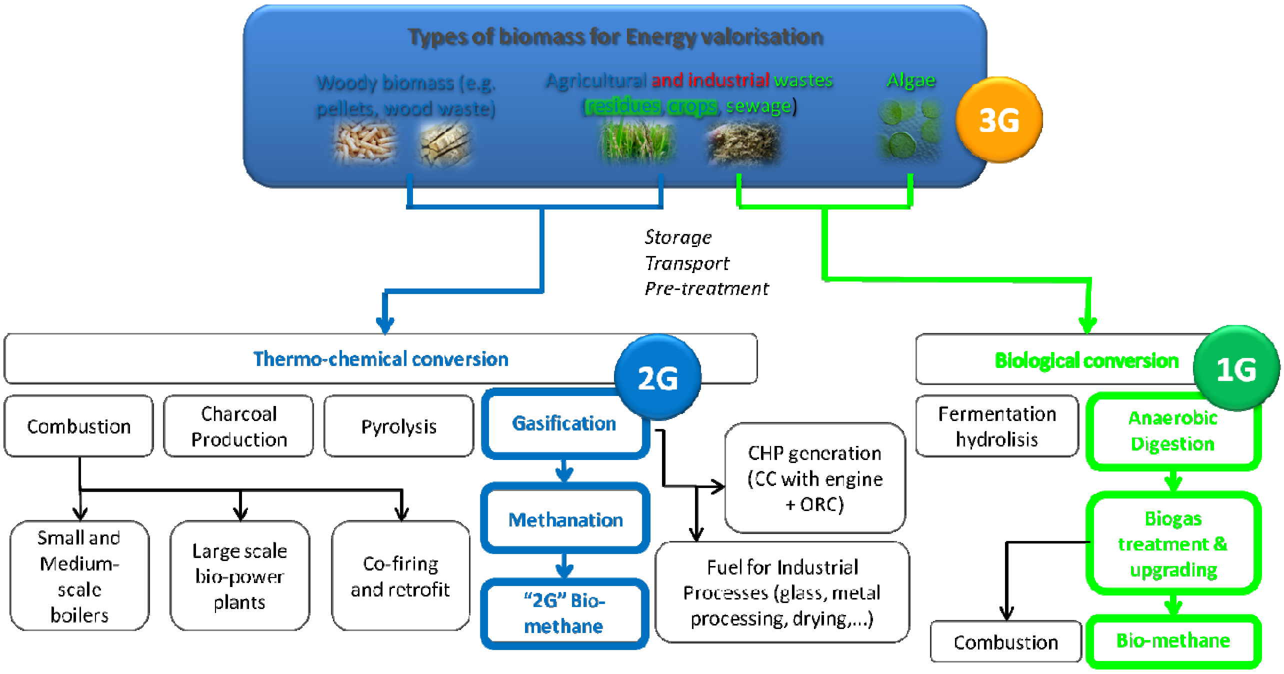

Figure 19 – Biomethane production routes : Focus on biomethane from gasification and anaerobic digestion. Source : GDF SUEZ.

Generally speaking, the main objectives of available LCA on biogas and biomethane are:

1. to verify the environmental performances of existing biogas/biomethane routes, in particular in terms of greenhouse gases emissions (16), (17), (18), (15), (19), (20),
2. to identify potential trade-offs between environmental impacts (15).

In the case of new pathways, such as second generation biomethane, LCA is also used as an additional criteria for the design of the process and supply chain, together with technical and economical criteria (21).

In terms of greenhouse gases emissions, the vast majority of published results demonstrate a reduction when biogas or biomethane is substituted to fossil resources, such as natural gas or diesel oil. However, the GHG assessment of biomethane routes is significantly different from one type of substrate to the other:

- for biomethane produced from anaerobic digestion, the lowest emissions rates are related to pathways using wastes as substrates: at least 65% of reduction over fossil fuels (15) and up to 97% (17);
- GHG emission levels are higher in the case of dedicated crops, and thus the advantage of biomethane over fossil fuels is lower in that case: up to 60% (20);
- Biomethane produced from second generation production pathways shows also high GHG emissions reduction, around 80% depending on the reference (19) (21).

Results are also sensitive to some methodological and technical assumptions, in particular:

- The method used to account for digestate, in the case of anaerobic digestion; depending on the approach used, the results of the GHG assessment may differ, and even be negative. The two potential approaches are: (i) either to consider the digestate as a co-product and thus to allocate a part of the impact both to the biogas and to the digestate based on a physical or economical allocation key; or (ii) to substract the avoided impacts due to the valorization of digestate (avoided emissions from using the manure instead of just storing it and avoided emissions due to the use of digestate to replace agricultural inputs).
- The level of methane leakages, for example at the purification step (from biogas to biomethane). Most of the studies consider that there are no methane leakages at the biogas production step.

Regarding other impact categories, some studies claim that biomethane has more impact than fossil fuels. This is the case for example for acidification, eutrophication or photochemical ozone formation (15).

The interest of using LCA in the case of biomethane is thus to quantify the actual benefits of this alternative to fossil resources and also to enlighten the potential pollution displacement to other environmental impacts. If this is the case, the decision maker should take into account the relative importance of the various impact categories in the final choice or decision.

Chapter 3 - How to improve LCA and its use towards a more sustainable natural gas chain ? Recommendations

Even if LCA is more and more used by the industry, its use may be further improved:
- by improved data collection, in order to improve the existing databases,
- by further work on environmental impact indicators : consensus is needed on how to assess the various impacts (e.g. GWP),
- by increasing the robustness of LCA in order to compare natural gas with other fuels in a relevant and consensual way.

Better design: Support Research and Development and investment
LCA may be applied to future technologies and pathways, in order to:
- Assess potential impacts of new supply chains, such as biomethane or non conventional resources. In this way, it may also be applied to compare various prospective scenario.
- Evaluate environmental performances of technical innovations

Better monitor: Accounting for environmental impact modifications due to evolutions on the natural gas supply chains
With periodically updated assessments, LCA can be used to evaluate the influence on environmental impacts of:
- The evolution of the supply mix (LNG vs. pipeline transportation, new supply chains…),
- Observed technical improvements (e.g. reduction of leakage rates at storage facilities, improvements of energy consumption of compressors, maintenance or industrial safety programs…).

Better communicate: A standardized methodology to promote the environmental performance of natural gas and meet stakeholders expectations
As LCA is widely recognized as a relevant methodology for environmental assessments, associated results may be used to promote the environmental performances of natural gas:
- On all impact categories, but especially on impacts where Natural Gas is competitive (such as local pollution)
- Environmental information will influence on the choice of energy by final customer
  - It is therefore crucial to deliver scientific and robust information
  - Results can be used to enhance the quality of existing reference databases.
- LCA is a way to demonstrate the environmental relevance/correctness of the decisions taken (against the NIMBY syndrome)

As mentioned above, Life Cycle Assessment of the gas chain is a method to quantify and evaluate environmental impacts associated with the whole activities from the exploration and production to the use of natural gas (and possibly biogas). Since LCAs are increasingly used as references when producing environmentally related legislations and regulations, its results and performance shall not be subjects to controversial discussions, especially if used in our case to compare the environmental performances of different energies.

In the core of the PGC A SG 3 work, the following issues have been identified as potential sources of improvement:

Harmonization of indicators/improved data collection

The IGU work focused on 4 environmental impact indicators which were seen as being relevant and possible to study at this stage by the industry:

- Climate change potential: CO_2, CH_4, N_2O
- Acidification potential: NOx and SOx
- Non renewable energy depletion
- Water consumption / water footprint

The main issue of concern when working on LCAs is the availability of robust and comparable data. Most of the time data are heterogeneous and part of them are extracted/recalculated from very different sources: questionnaires, Companies reports, Universities or Institutes studies, other LCAs or existing databases.
Definitions and methods for calculating the different factors needed for the global calculation shall be, if possible, harmonised, using standards or guidelines produced by independent organisations such as the International or European Standardisation Organisations ISO or CEN or Agencies (International Energy Agency A, U.S. Environmental Performance Agency…).
When such reference documents do not exist, harmonisation work shall undertake work such as the activity carried out by MARCOGAZ in Europe for developing common industry methodology to define methane emissions from transmission or distribution networks.
When adopted internally by the Industry, the guidelines developed shall be used as basis for international standards.
In case data are given or extracted from studies or Companies Annual Environmental Reports, harmonisation work has to be carried out to understand the data provided.

Recommendation: Due to the raising importance of environmental energy issues, it is recommended that the gas industry, through IGU, could support the creation and maintenance of such a LCA database to be used as a reference and used by its members when necessary. The first difficulty is the availability of data : there is a need for a stronger involvement of the industry in data collection.
An harmonisation scheme for data collection is also needed as well as the minimum list of data to be collected (and definition) and level of representativeness of data for each step. (in order to compare between supply chains)

Standards on CH_4 emissions assessment methodology is needed for the natural gas chain and could thus be a relevant first step.

Further work on indicators / consensus needed (e.g. GWP)

As mentioned above, the indicators studied represent the main environmental impacts but are in limited numbers for a comprehensive LCA.
Other relevant indicators could be discussed and evaluated such as dust or particulates, carbon monoxide, different organic volatile compounds, solid waste production or water use (which will increase with the introduction of new pathways – such as non conventional resources or biomass based methane).

Increase robustness of LCA in order to compare NG with other fuels

There is a common agreement that natural gas is environmentally better than other fossil fuel (e.g. around 45 % less CO_2 emission than coal during the full life cycle).
Nevertheless comparison with other fuels (oil, coal, uranium) needs that LCA's produced by different parties are sound and comparable. Soundness of the studies is normally ensured by third party check (peer review) according to ISO 14040 standards series.
But different boundaries, environmental indicators and uses can make any comparison difficult and controversial. The definition of similar utilizations is necessary (e.g. heating/hot water production, electricity generation by centralized power plant, transport using the same means of transportation).

Gas chain new activities

Issues such as biogas/biomethane production and distribution, carbon capture and storage, shale gas extraction or LNG for transport should be added to the current work to complete a full understanding of tomorrow's gas chains.

Concluding remarks

Life Cycle Assessment is a raising issue :

- There are increasing expectations for environmental information from stakeholders,
- LCA is today widely used in other industries, e.g. the automotive industry, the plastics industry, the food industry or the chemical industry,
- LCA is more and more used in decision processes, even at the political level : for example in the European regulatory processes, applied to LNG for trucks in the USA,…
- LCA is a also a relevant tool for finding and quantifying potential impact reductions, e.g. energy savings or to benchmark different energy pathways.

So far, the focus was mainly on GHG emissions and the natural gas industry was looking at the emissions from a safety issues point of view. LCA applied to natural gas is mostly used to benchmark natural gas with other energy pathways. It may also be used to compare different processes options to support decision making.

Still there is need for improvement, in terms of data and methods:

- No reference database exists for the natural gas industry
- How to collect and store data ? What is the role of IGU in such a task ? Need for an external consultant ? How to maintain and update the database ?
- Agree at the industry level on a set of data to be collected at each step of the chain (e.g. leakages, energy consumption, pollutant emissions, water use…)
- Need for a step by step approach : the question is different for the e&p and for the downstream steps such as transport and distribution.
- Harmonization may be possible for the T&D but another approach is needed for E&P (definition of a relevant typology : country by country, technology, geology, timing, average vs. best practices…).

New chains (shale gas, renewable gases) will imply to consider new impact categories, in particular water footprint or impacts related to local pollution.

The practice of LCA is growing in the natural gas industry: LCA is as well a source of knowledge and communication as it is a source of innovation and strategy, based on solid scientific foundations. Indeed, LCA is an efficient tool for energy analysis: it draws a more complete picture than one focused solely on stack or tailpipe emissions, it allows direct comparison of dramatically different options and includes methods for evaluating a wide variety of burdens. Life Cycle Analysis is thus well suited to analyze the effect of unconventional sources on the environmental profile of natural gas systems.

A key issue for a broader use of LCA is the availability of relevant data. As methane emissions are one of the most impacting parameters, a first step toward a database from the natural gas industry could be to build a consensual method to assess those methane emissions all along the natural gas chains.

Definitions / Glossary

APG	Associated Petroleum Gases
BAT	Best Available Techiques
BP	British Petroleum
CBM	Coal bed Methane
CNG	Compressed Natural Gas
EPA	Environmental Protection Agency
GHG	GreenHouse Gases
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Analysis (based on ISO 14040 definition)
LFO	Light Fuel Oil
LNG	Liquefied Natural Gas
LBG	Liquefied BioGas
MIT	Massachusetts Institute of Technology
NAC	North African Countries
NGV	Natural Gas Vehicle
NSPS	New Sources Performance Standards
RME	Region Middle East

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Appendix 1 - Results from the data collection within IGU members: comparison with literature and LCA databases

The literature has allowed to identify dominant impacts and parameters, to deduce the most efficient technologies and sources of natural gas production that will enhance the sustainability of gas supply chains. As data is a key point, the LCA study group launched a data collection among IGU members, to try and initiate a work within the natural gas industry in order to build a common database, as recommended by the 2006 IGU report on LCA.

One of the goal of this data collection was to update the information available on environmental impacts of worldwide natural gas chains in terms of:

- Climate change, based on greenhouse gases emissions,
- Energetic resources depletion, based on type and quantity of energy consumed,
- Terrestrial acidification, based mainly on SO_X and NO_X emissions,
- If possible water resources depletion.

An Excel sheet has thus been sent early in 2013 to all relevant IGU members in order to collect the related data at each step of the natural gas chains.

Contributors and scope covered by data collected

Data have been collected amongst a dozen of industrials :

- Members have provided data in the framework of Marcogaz or IGU membership:
  - **SNAM RETE GAS** (GNL Italia, SNAM Rete Gas, Stogit, Italgas & Napoletana Gas)
  - **FLUXYS**
  - **EUSTREAM**
  - **GDF SUEZ** (data collected from LCA studies carried out by GDF SUEZ for GRTgaz, Storengy, GrDF)
  - **GASUM OY**
  - **ENAGAS**
- IGU members who have provided additional data are:
  - **EDISON STOCCAGGIO SPA**
  - **SPP STORAGE**
  - **ENI**
  - **SEDIGAS**
  - **OSAKAGAS, on behalf of Japan Gas Association**
  - **SONATRACH**
- Other industrial actors whom published data fueled our primary data collection:
  - **STATOIL**
- Other IGU confidential data.

The geographical perimeter of the data collected is represented Figure 15

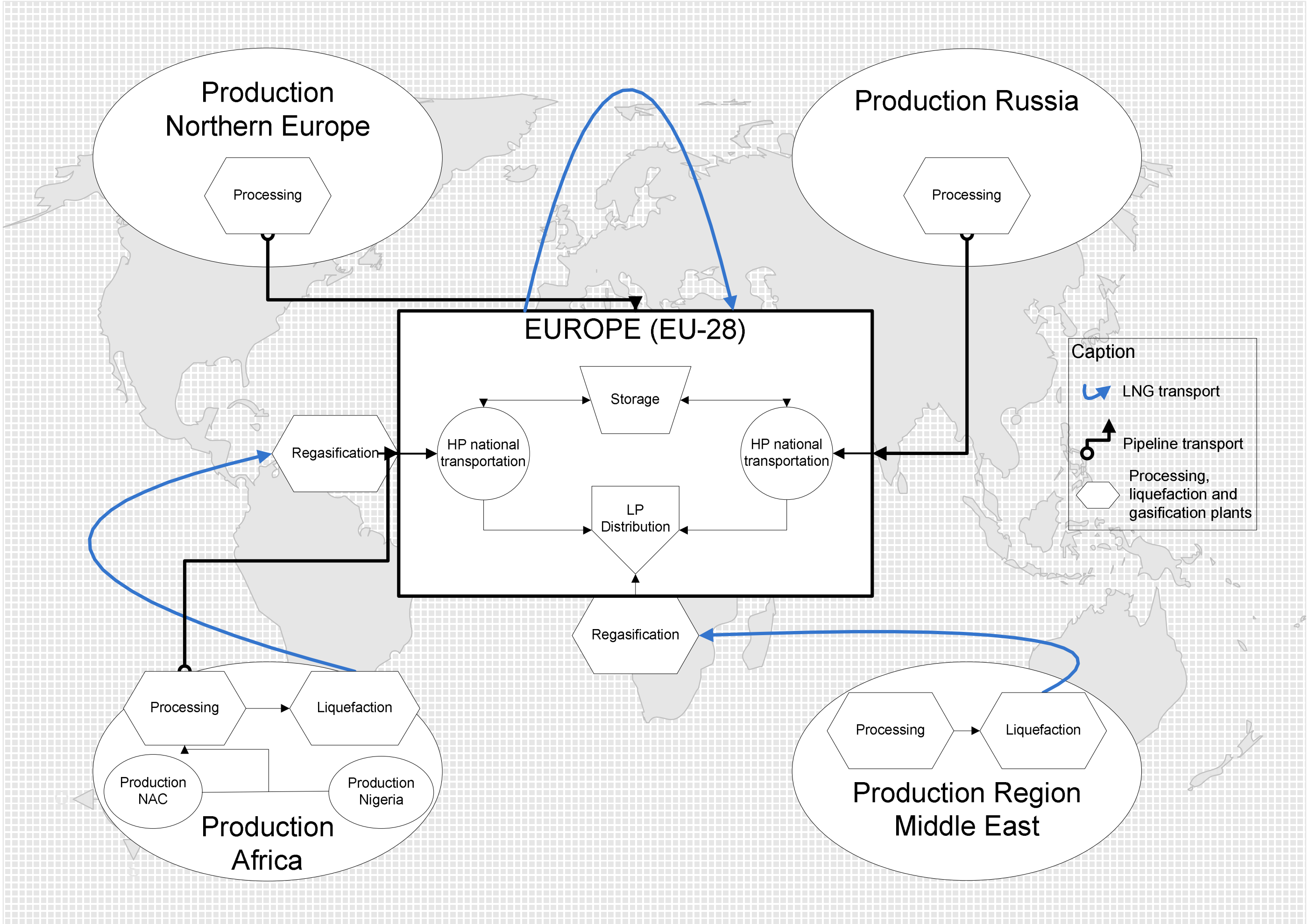


Figure 20.

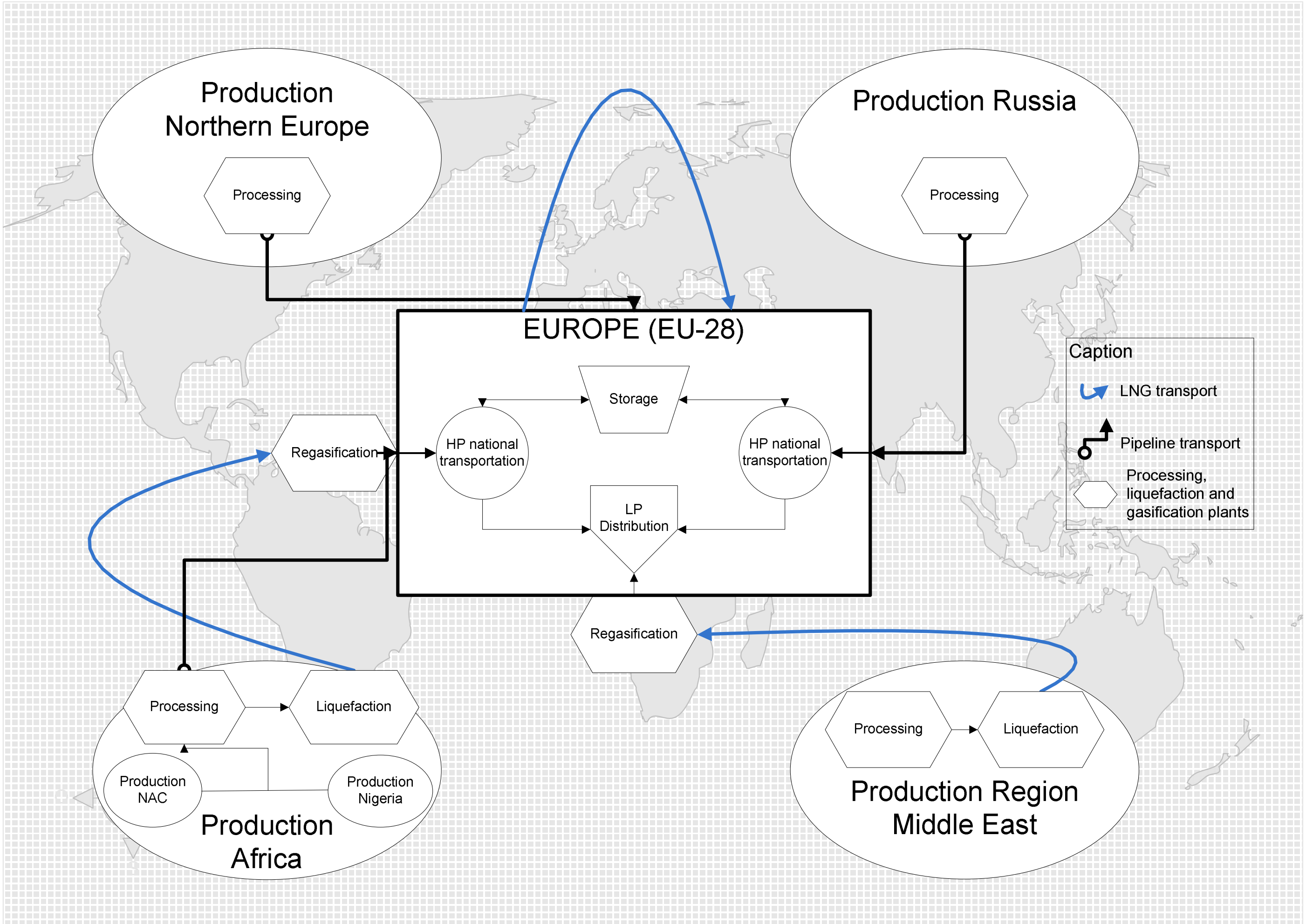


Figure 20- Geographical perimeter of the Marcogaz-IGU LCA data

To carry out the LCA of the natural gas chains, remote sources of gas production have to be taken into account. Indeed, natural gas consumed in the European area is produced in Europe, Norway, Russia, North Africa, Nigeria and the Region Middle-East. We thus have to take into account the supply routes from those countries to the country of consumption.

- ⇨ Consequently, the data collection for production & processing, long distance transportation and LNG transportation steps was conducted at a global scale to include the main production sources.
- ⇨ On the other hand, storage, national high pressure transportation and national low pressure distribution steps are assessed in a European perimeter.

Data have been collected from 2011 to 2013 and range from 2009 to 2013. The majority (over 80%) of the collected data range from 2011 to 2013.

Some data from the previous Marcogaz study have been used due to a lack of data (e.g. Nigerian and British production activities). These are extracted from the Ecoinvent database, collected and treated from 2000 to 2004.

As it has been shown previously, the construction and deconstruction of equipments of the gas industry (wells, plants and pipelines) shouldn't be neglected for the assessment of environmental impacts, and energy consumptions from domestic (administrative: offices, staff travels…) activities are negligible in comparison of industrial activities, except for the distribution step. These conclusions however relate to specific and limited activities of the gas chain and do not necessarily mean that the same proportions will be found in the overall results of this LCA.

1- Considering those conclusions, this study focuses on industrial activities. Emissions and consumptions from administrative buildings and vehicles are not taken into account.

2- The exploration step is not included in this study. Indeed, exploration is made by petroleum companies for both oil and gas. It is very difficult to allocate the impacts of an exploration campaign, when neither oil nor gas is found. Even if that is possible, data concerning the impacts (energy consumption, emissions to environment) of the exploration stage are not known by gas companies, but only by petroleum companies.

3- The utilization step is not included in this study as well.
The final use of natural gas represents the majority of the impacts generated by the natural gas chain in the previous Marcogaz study. The goal of this study is to assess the impacts of the natural gas chain itself and to constitute a tool of knowledge and improvement for the related industrial actors. Considering the utilization step in our LCA wouldn't fit these requirements.

4- Building and decommissioning of gas equipments are not included in this study, but the impacts of those activities will be considered through a sensitivity analysis.

5- Every atmospheric emissions and incidents from industrial activities are taken into account in this study. This includes:

- Fugitive emissions (e.g. all small leaks from flanges, pipe equipment, valves, joints, etc. that are more or less continuous sources).
- Pneumatic emissions (all emissions caused by gas operating valves, continuous as well as intermittent emissions).
- Vented emissions from maintenance (emissions from normal or planned operating conditions where significant volumes of natural gas is released to the atmosphere from the gas network. This includes release through stacks; blow off valves, pressure release and flushing of turbines and emissions due to normal maintenance inspection and control).
- Incidents vents (emissions from unplanned events. This will normally be from failures of the system due to third party activity and external factors normally outside of the control of the gas company).

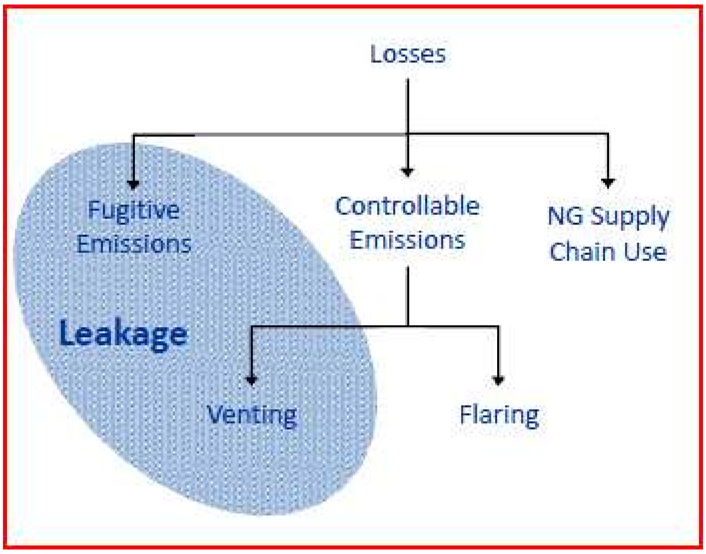


Figure 21 – Types of atmospheric emissions emitted by the natural gas industry

- Flares (e.g. natural gas emissions where methane released is burned during normal operations)
    - ⇨ Those data are used to establish a rate of natural gas emissions by step and by area or country.
- A specific attention is also given to CH_4 and NO_X emissions.

Comparison of main parameters based on data collected from the industry and from the literature

Through the data collection, Marcogaz and IGU members could inform the inflows and outflows of their activities via four categories:

- General data: Main specifications of the installations, flows of natural gas produced, transported, etc.

- Energy consumption: Natural gas autoconsumption, electricity consumption and other types of fuel consumption, such as petrol, diesel, LFO, APG…
- Atmospheric emissions: Emissions from flares, leakages, vents…
  Quantification of NOx and CH_4 emitted
- Water consumption: Water withdrawal and discharges, water treatment if available
- Chemical consumption

Data related to energy consumption and atmospheric emissions were most of the time complete but data related to water flows and chemicals are still rare. These categories have been chosen to represent the inflows and outflows of the natural gas chain.

Data from those sources where used when they when they could be verified, recent, adapted to the scope of data collection and only to fill the lacks of the primary data collection. Only few sources could fit these requirements:

- [8] Greenhouse gas life-cycle emissions study: Fuel Life-Cycle of U.S. Natural Gas Supplies and International LNG, November 10, 2008. Prepared by Advanced Resources International, Inc. and ICF International for Sempra LNG
- [17] Life Cycle Inventory of Natural Gas Supply, S.Schori, R.Frischknecht, Uster, September 2012
- [22] The natural gas chain – Toward a global life cycle assessment, M.N. Sevenster, H.J. Croezen, Delft, January 2006
- Data extracted from the Ecoinvent database will be also presented in this comparison.

Data from Schori et al. study [17] have been recently updated and are very well adapted to the scope of this data collection. These were thus integrated directly in the industrial data collection (Marcogaz 2013), especially to fill the lacks about production activities in the Russian federation.

The first database is not included in this report, as it is still to be completed, but is a first step towards a broader database from the natural gas industry on environmental information related to natural gas supply chains.

Three main observations can be made on the comparison between existing generic databases and data collected from the industry:

- On the one hand, data collected from the industry are more recent than data from the literature and are more likely to reflect the industrial state of the art. On the other hand, data collected from companies are sometimes incomplete to perform a full assessment. Industrial and literature data could thus be used together to obtain a complete data set.
- Technological improvements have led to a reduction of emissions and consumptions from the upstream gas chain. Considering the downstream gas chain, inflows and outflows have changed (e.g. from gas consumption to electric consumption for national transmission with the apparition of electric compressor stations), but the total energy balance is about the same.
- Main parameters of the gas chain vary widely from an area to another: the European gas industry shows much lower consumptions and emissions than the Russian or the North American industries for example. This can be explained by the difference between technologies: improvements have been made over time, but countries renew their equipments with various timeframes, depending on the strategic orientations of companies and on the geopolitical and economic context of the area.

As a consequence, the natural gas industry shall mobilize through gas associations like Marcogaz and IGU to improve this data collection. Additional data improvements will further increase the accuracy and representativeness of LCA results :

- More gas industrials should collect and transmit their data to enlarge the knowledge of the gas chain, and more specially the knowledge of their activities.

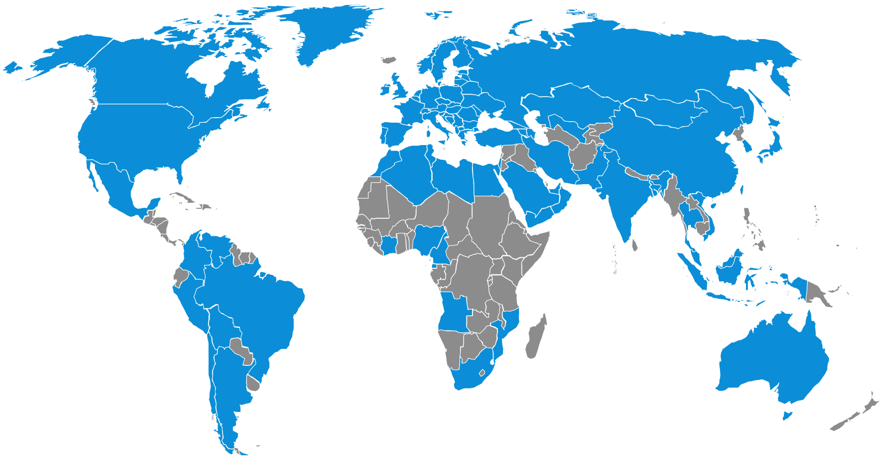
- Recent information should be available to allow the most relevant analysis of a particular technology, production source…

- The monitoring and the methodology of data collection has to be common: companies should collect the same data: periods, units and activities…

- Generic databases should take into account the geographical variation of parameters.

Such requirements can't be based on the good will of companies: the gas industry has to promote LCA and show that it can be an efficient tool for decision making and innovation: the consistent modeling approach of the LCA framework has already allowed for incorporation of latest research to produce precise results on a common basis and flexible, bottom-up modeling approach has allowed LCA practitioners to respond to questions from government, academia, industry and NGO stakeholders.

NOTES



The International Gas Union (IGU) was founded in 1931 and is a worldwide non-profit organisation promoting the political, technical and economic progress of the gas industry with the mission to advocate for gas as an integral part of a sustainable global energy system. The IGU has more than 142 members worldwide and represents more than 97% of the world's gas market. The members are national associations and corporations of the gas industry. The working organisation of IGU covers the complete value chain of the gas industry from upstream to downstream. For more information please visit **www.igu.org**

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