SIXTH FRAMEWORK PROGRAMME

Project no: **502687**

NEEDS

New Energy Externalities Developments for Sustainability

INTEGRATED PROJECT

Priority 6.1: Sustainable Energy Systems and, more specifically,
Sub-priority 6.1.3.2.5: Socio-economic tools and concepts for energy strategy.

Deliverable - RS 1c WP 2

Tasks 2.3-2.6. Burdens, Impacts And Externalities From Natural Gas Chain

Due date of deliverable: August 31 2007
Actual submission date: November 13 2007 Revised November 23 2007

Start date of project: 1 September 2004 Duration: 48 months

Organisation name for this deliverable: **FEEM (in collaboration with POLITO and OME)**

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	**PP**
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Abstract

The aim of this technical report is to complete the analysis of burdens and impacts of the natural gas production chain. The incompleteness of available information prevented us from reaching a complete assessment of probabilistic externalities in this sector. However the available data and information seem to suggest that the magnitude of probabilistic externalities in the natural gas chain is likely to be very small.

Operational externalities are present, but again, being the sulphur and particulate content of natural gas negligible, their importance is much lower than for other fossil fuel. GHG-related externalities are more substantial, but the current trend of improving standards prompt hopes that also these impacts will be substantially reduced in the coming years.

This assessment exercise shows that externalities related to the natural gas chain are not negligible, but still relatively quite small, and slightly declining in the coming decades. This conclusion stems from an in-deep assessment of operational externalities related to the extraction of natural gas for European consumption and to its transportation to Europe, and has generated overall externality values which range which range between 0.32 Euro per ton of natural gas transported to Europe in 2020 in the Low demand scenario and 1.71 Euro per ton of natural gas transported to Europe in the base year (2004).

Table of contents

Figures and Tables in the text

Burdens, Impacts And Externalities From Natural Gas Chain

1. Introduction

The aim of this Technical Report is to complete the analysis of burdens and impacts of the natural gas production chain. A previous report covered the operational burdens and impacts of pipeline gas transportation and of the downstream phases (shipping and re-gasification) of LNG transport, and the probabilistic burdens and impacts related to downstream LNG transport.

This report will try to collect the relevant information related to the phases not covered by that report: namely the exposure to accident risk of non-European gas pipelines and of the liquefaction phase of the LNG process.

Unfortunately this information is hard to find. Gas companies in general claim to work at the highest safety standard possible and in most cases officially they simply rule out the possibility of an accident; design accident probabilities are considered business-critical confidential information.

Thus, we were unable to find reliable information for African and middle East pipelines and for gas extraction fields. We could however find some reliable information about reported accidents in the Russian gas pipeline network and about accidents at gas liquefaction installations.

Moreover this note will complete the information about operational externalities from gas extraction and transportation. This boils down to combining emission factors of the major pollutants (NO_x, SO_2, volatile organic compounds, greenhouse gasses) per unit of gas produced or transported at regions relevant for gas import to Europe, by the corresponding externality per ton of pollutant used in NEEDS. Externality values for local pollutants take into account health impacts, environmental impacts, and impacts on crops and materials, while those for greenhouse gasses are marginal damage costs computed by an ad hoc model. Moreover, non-GHG externalities are differentiated according to the dispersion and deposition patterns of emissions originated in various region in Europe and surrounding regions. Unit emission factors are in general taken from Ecoinvent; externalities per ton of pollutant are taken from Ecosense. The only exception are operational externalities from LNG tankers, which are derived using the TEAMS model.

The final step of our externality assessment for the natural gas chain entails plugging the unit externality values into scenario projections of natural gas production and import to Europe for the present and for selected future years, under reasonable assumptions about energy markets trends. This step was performed on the basis of natural gas demand and import flows scenarios developed by OME, and generated overall externality values which range between 0.32 Euro per ton of natural gas transported to Europe in 2020 in the Low demand scenario and 1.71 Euro per ton of natural gas transported to Europe in the base year (2004).

The next two sections report on the information gathered about probabilistic burdens and impacts, Section 4 covers unit operational externalities, Section 5 reports on overall externality computations and Section 6 concludes.

2. Pipeline gas transportation

As noted in the previous technical report about gas impacts and burdens[1], traditionally the European model of gas import infrastructure has been based on the use of pipelines, due to the geographical position of Europe with respect to the major gas exporting countries. The vast majority (94%) of EU imports reaches the EU via high pressure pipelines from Russia, (43%) Norway (27%) and North Africa (23%).

The technological standards of these infrastructures are uneven and no overall transparent assessment of their reliability is available. The claim generally made by the owners and operators of these pipelines is that they meet the highest standards in terms of safety design and maintenance.

The reliability of these statements is hard to verify. One can reasonably trust these optimistic statements only for new infrastructures or for infrastructure under construction, and possibly for submarine pipelines, which must be built with substantial redundancy to cope with the conditions of the sea floors where they are installed and with the resulting difficulty to carry out routine and extraordinary maintenance. In fact, as stated in the previous technical report, the submerged sections consist of single uninterrupted pipes without flanges nor valves; therefore, nowhere along the submerged section of the pipeline a leakage can take place (the chances of cracking or puncturing the pipe are also negligible).

North Africa

Following this line of reasoning, in want of more accurate information, we can regard as posing negligible risks the Greenstream pipeline, which runs for 520 km on the Mediterranean Sea floor, between the Libyan compressor station of Mellitah and the receiving terminal of Gela, Sicily. The 32’’ pipe can carry 8 billion cubic meters per year, and has been completed in 2004. Similar standards will be most probably attained by the two main Africa–Europe pipeline inter-connector projects currently under development, namely the GALSI pipeline, expected to connect Algeria to Sardinia[2] and thence Tuscany by 2008, and Medgaz, expected to connect Algeria to Spain[3]. GALSI estimated initial capacity is 21.8-28 million cubic meters/day. Works may start in 2008.

---

[1] Technical paper n°2.3 - RS 1c “Gas Transportation: Burdens and Impacts.”, September 2006.

[2] Current plans foresee an onshore pipeline from Gassi R'Mel to El Kal, Algeria, then an underwater section to Cagliari, Sardinia, an onshore section to Olbia, Sardinia, then a final, offshore pipeline to Castiglione della Pescaia, Italy.

[3] Medgaz will link Beni Saf, Algeria to Almeria, Spain, with an eventual extension to France. In September 2002, the consortium completed a study of the line's feasibility, but delays have pushed initial construction on the project to July 2005.

Medgaz, which should be completed by 2008, will have an initial capacity of 11 million cubic meters/day, increasing to a maximum of almost 44 million cubic meters/day.

Little less confidence is perhaps deserved by the safety standards of the existing Africa-Europe connections due to their age; however the continuing projects of capacity upgrading seem to signal that the interest of gas suppliers and costumers for these infrastructure is still high, and thus one can reasonably hope that safety standards will be kept up to date as well. However, to our knowledge no public data is available in order to substantiate quantitatively these insights.

There are two natural gas pipeline connections between Algeria and Europe. The 1080 km, 65.7-million cubic meters/day Trans-Mediterranean (Transmed) line runs from Hassi R'Mel, via Tunisia and Sicily, to mainland Italy. Completed in 1983 and doubled in 1994, there are plans to construct an additional compressor station along the Transmed that could increase capacity to 98.5 million cubic meters/day. The other connection is the 1,600 km, 23.2 million cubic meters/day Maghreb-Europe Gas (MEG). MEG, completed in 1996, connects Hassi R'mel with Cordoba, Spain, via Morocco, where it ties into the Spanish and Portuguese gas transmission networks[4].

Russia

The technical features of Russian pipelines to Europe have been discussed extensively in Technical paper n°2.3 - RS 1c, along with their operational burdens and impacts. Here we focus on adding some information about their probabilistic burdens.

The available data do not allow to draw any robust conclusion about the probability distribution of accidental leakages from Russian pipelines. However, they at least allow us to get an idea about the current and past trends in maintenance standards of these pipelines.

Figure 1 illustrates the current age distribution of Russian gas pipelines. It transpires that these pipelines are on average rather old: only 41 percent are less than 10 years old, and a substantial share of them, 14 percent are older than 30 years.

[4] The capacity of MEG is currently being expanded to 50.4 million cubic meters/day.

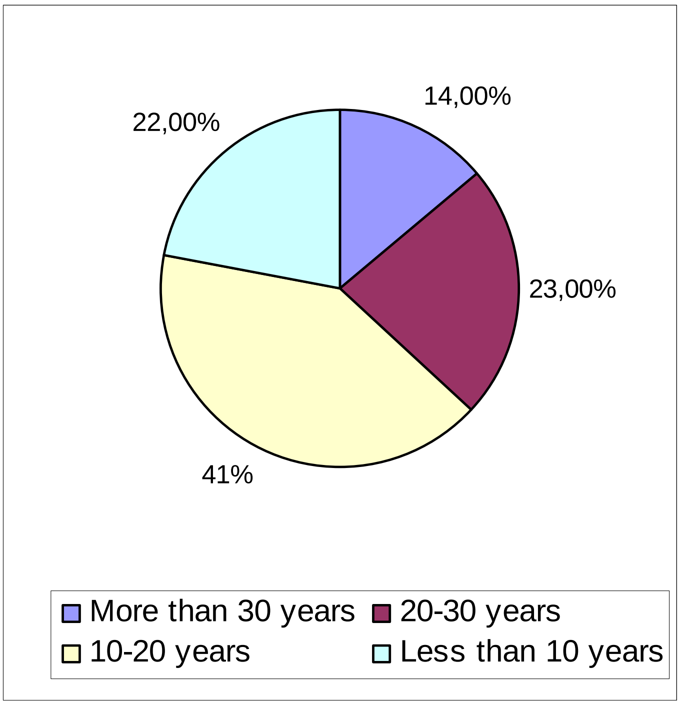

Figure 1 Age structure of Russian Pipelines. Source: OME

Figure 2 however, highlights the fact that the situation is slowly improving. After an underinvestment phase in the ’90, the constantly rising demand for Russian gas has brought in the financial means to upgrade not only the capacity but also the maintenance and safety standards of the Russian gas exporting network. This results in a downward trend in the frequency of ruptures in the last 5-8 years. This evidence supports the insight that Russia may soon reach the European safety and maintenance standards if the current level of revenues from gas experts is sustained in the future.

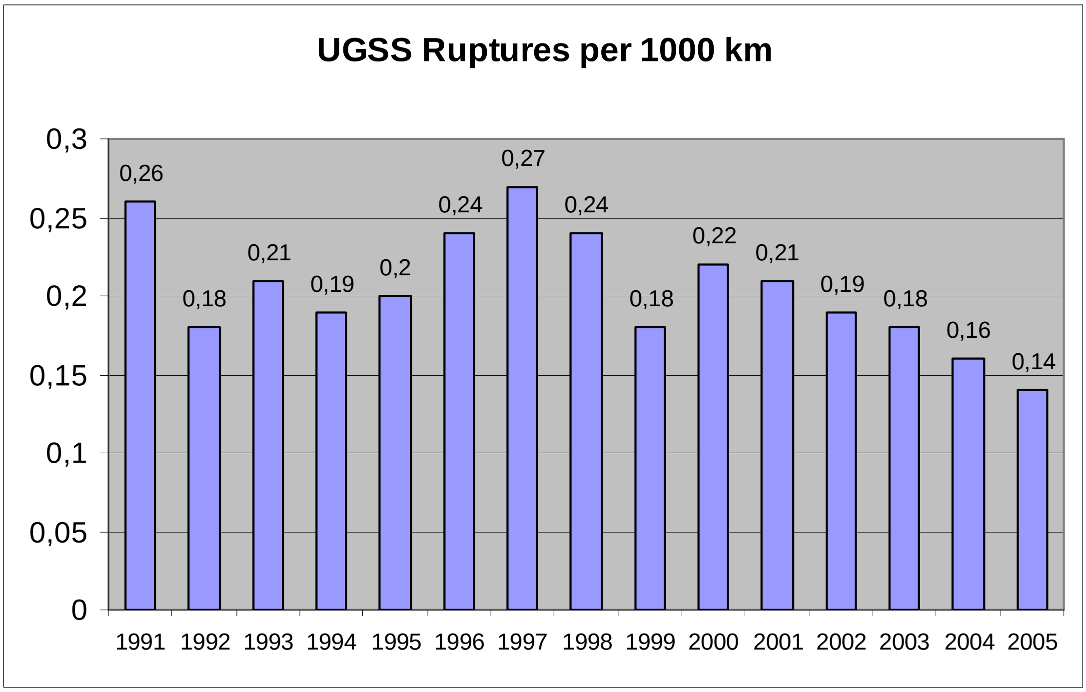

Figure 2 Rupture frequency for Russian gas pipelines. Source: OME

3. LNG liquefaction

As noted in Technical paper n°2.3 - RS 1c, a significant fraction (6%) of the natural gas consumed in the EU is carried to destination by means of Liquefied Natural Gas (LNG) tankers from Nigeria and the Persian Gulf. LNG imports in Europe are expected to increase in the next decades, as they are generally considered as an important way to improve flexibility and security of supply of the European energy system.

The downstream phases of the LNG chain have been extensively discussed in that technical report. Here we briefly focus on the upstream phase, namely the liquefaction of natural gas at the ports of departure.

The liquefaction process is known to be energy intensive, as it requires energy to cool down gas to its liquefaction point data on emissions from liquefaction plants are not widely available. However, they are included in the Ecoinvent database.

As to probabilistic burden and impacts, only four accidents have been recorded in the Midhas database. Among those four accident the one of some relevance is the one occurred in Skikda, Algeria.

On January 19th , 2004, in Skikda, a steam boiler that was part of an LNG liquefaction production plant exploded, triggering a second, more massive vapour-cloud explosion and fire that took eight hours to extinguish. The explosions and fire destroyed a portion of the LNG plant and caused death, injuries, and material damage outside the plant's boundaries.

The plant had six LNG-producing units (trains), LNG storage tanks, and administration and operations buildings. The plant uses steam boilers to make high-pressure steam for its steam turbines. These turbines supply power to the plant's refrigerant compressors that are used to liquefy the natural gas.

The explosion of the gas vapour cloud occurred between two sections of one production train: 1) where natural gas liquids (propane and ethane) are separated from methane, and 2) where methane is liquefied. Fire destroyed three LNG trains, but did not damage any LNG storage tanks or the remaining three trains. 27 people were killed and 74 wounded. Total economic damages for the plant were estimated to amount to 578 million Euros. Note that all those affected were workers involved in the LNG plant operations. The train were the explosion was originated (train 40) was actually scheduled for demolition. In 1974 there had been a previous accident in Skikda, in this case without casualties. Mercury corrosion at liquefaction plant caused the rupture of tubes used in heat exchangers causing plant to shut down.

In 1983, in Bontang, Indonesia, a heat exchanger ruptured violently during start-up operation, due to a valve that failed to open. The exchanger experienced pressures three times its design pressure before rupturing. Debris and coil sections were projected up to 50 meters away. Shrapnel from the column killed three workers. The ensuing fire was extinguished in about 30 minutes. This incident occurred during dry-out and purging of the exchanger with warm natural gas prior to introducing any LNG into the system, so no LNG was actually involved or released. The Nigerian accident actually consisted in a three-week interruption of the activities at the plant after the local population broke in and destroyed the control room. The accident recorded in the miDhas database are summarised in Table 1 below.

Date	Location	Incident Type	Related dangerous events	Killed	Injured	Leak (tonnes)
19/01/2004	Algeria, Skikda	Mechanical failure	Fire, explosion	23	74	
23/07/2001	Nigeria, Bonny	Sabotage/Vandalism	none	0	0	0
14/02/1983	Indonesia, East Kalamtan, Bontang	Mechanical failure and human error	LNG release, fire	*3*[5]	0	170
1974	Algeria, Skikda	Mechanical failure	fire	0	0	0

Table 1 Major recorded accidents in LNG liquefaction facilities. Source: miDhas

From these data it is hardly justifiable to extract any probability distribution of accidents. By dividing the Skikda fatalities (the only ones actually related to LNG liquefaction operation) by the total LNG production, one can have an idea of a possible fatality rate, under the heroic implicit assumption that Skikda liquefaction plant is representative of all LNG liquefaction plants in the world. The anomaly of this accident, however was that the train were the accident started was scheduled for demolition; in other words, in typical, normal condition such a train should not have been operational. Therefore the resulting fatality rate should be taken as an upper bound of the possible fatality rate in the upstream LNG industry. The resulting fatality rates are collected in the first column of Table 2, while the second column relates the casualties the cumulated production of the Skikda plant only. The third column relates the casualties to the hours of activities, assuming that the plant has been operating without interruption (bar 30 days a year for maintenance) from 1973 to the day of the accident (19/01/2004).

	on total world production	on Skikda's production	on Skikda's hours of activity
Injuries	0,03	0,67	2,96E-04
Deaths	0,01	0,25	1,08E-04

Table 2 Fatality rates on cumulated production (number of casualties per Bcm of total cumulated production to 2006, and number of casualties per hour of activity).

[5] The miDhas database reports no deaths for this accident, but a different source (CHV International, 2006) reports three workers fatally injured. However the same source points out that in this accident no LNG was involved, as it took place before LNG was allowed to flow into the plant.

4. Operational externalities

An extensive catalogue of unit emissions from gas extraction and transportation is available in the Ecoinvent database. Ecoinvent data are extracted from a proprietary database. Therefore they are confidential and cannot be reproduced as they appear in their original format. In order to ensure their confidentiality while providing a result foreseen in any case by the project, these data have been combined with Ecosense data on externalities per ton of pollutant (which are also confidential).

Externalities vary with the different regions at which operations take place, due to the different deposition patterns of the pollutants and hence the different socioeconomic and environmental characteristics of the regions exposed.

Moreover, externalities vary with time. We used the most updated projections produced by NEEDS project. For non GHG pollutants, we used values for average height of release derived using EcoSenseWebV1.2 - 21.09.2007 (based on aggregation scheme "NEEDS_core_SIA" for Human Health Impacts, based on average meteorology - corresponding to emissions from all SNAP-Sectors). For GHG emissions external costs used are computed as Marginal Damage Costs of GHG, taken from MDC_Anthoff_V1.1 under the following assumptions: -"without equity weighting",-"average 1% trimmed", -"1% discounting". The exchange from US$ to Euro corresponds to ca. 1.35$ per €. More details can be found in Preiss (2007). The available projections cover 2010, 2020 and 2030 for GHG emissions, and 2010 and 2020 for non-GHG emissions. For the latter, 2020 values are used for 2030 as well.

Natural gas extraction

The results for non-GHG emissions of natural gas extraction in 2010 and 2020 are listed in Table 3 and Table 4 respectively while Table 5 lists the externality results for GHG emissions related to gas extraction activities in 2010, 2020 and 2030. Table 6 lists the averaged externality values to be used in the scenarios illustrated in Section 5. In order to keep our analysis as general as possible, we used a weighted average of onshore and offshore extraction externalities, were the weights in each year and in each scenario analyzed, are given by the shares in total European imports, of the various production areas for which it was possible to compute unit eternality values: Algeria (whose weights represent the Middle East-north Africa macro region), Norway, and a macro region which includes the Russian Federation and Azerbaijan. Thus the results shown in Section 5 are based on ten different sets of weights, capturing the relative relevance of the various production areas in each year and scenario.

	Norway	Algeria	Russia
Human Health			
NMVOC	0,002577	-4,9E-05	0,000829
NO_X	0,016204	0,006617	0,005914
PPM^{co}	0,000413	0,000253	0,000519
PPM^{25}	0,008104	0,004558	0,008273
SO_2	0,045442	0,033362	0,02376
Loss of Biodiversity			
NMVOC	-0,00012	-5E-05	-2,5E-05
NO_X	0,00398	0,000977	0,000429
PPM^{co}	0	0	0
PPM^{25}	0	0	0
SO_2	0,002038	0,000338	0,000345
Crops & Material			
NMVOC	0,000955	0,000221	3,68E-05
NO_X	-0,00022	0,000293	0,00042
PPM^{co}	0	0	0
PPM^{25}	0	0	0
SO_2	-0,00043	-0,00015	0,002222
Total			
NMVOC	0,003416	-4,9E-05	0,000841
NO_X	0,019962	0,006617	0,006762
PPM^{co}	0,000413	0,000253	0,000519
PPM^{25}	0,008104	0,004558	0,008273
SO_2	0,04705	0,033362	0,026327

Table 3 Unit External Costs [Euro per Ton] non-GHG emissions from natural gas production offshore (Norway) and onshore (Algeria and Russia), in 2010. Source: Own computations based on Ecoinvent and Ecosense data.

	Norway	Algeria	Russia
Human Health			
NMVOC	1,38E-03	1,91E-04	4,09E-04
NO_X	1,93E-02	6,22E-03	7,20E-03
PPM^{co}	4,11E-04	2,21E-04	4,87E-04
PPM^{25}	8,10E-03	5,35E-03	7,90E-03
SO_2	5,32E-02	3,41E-02	2,56E-02
Loss of Biodiversity			
NMVOC	-1,11E-04	-4,12E-05	-2,16E-05
NO_X	3,94E-03	9,51E-04	4,06E-04
PPM^{co}	0	0	0
PPM^{25}	0	0	0
SO_2	2,22E-03	3,89E-04	2,94E-04
Crops & Material			
NMVOC	5,86E-04	1,21E-04	1,94E-05
NO_X	7,28E-04	3,93E-04	3,76E-04
PPM^{co}	0	0	0
PPM^{25}	0	0	0
SO_2	-6,66E-04	-1,95E-04	2,09E-03
Sum			
NMVOC	1,85E-03	2,71E-04	4,07E-04
NO_X	2,40E-02	7,57E-03	7,99E-03
PPM^{co}	4,11E-04	2,21E-04	4,87E-04
PPM^{25}	8,10E-03	5,35E-03	7,90E-03
SO_2	5,47E-02	3,43E-02	2,80E-02

Table 4 Unit External Costs [Euro per Ton] non-GHG emissions from natural gas production offshore (Norway) and onshore (Algeria and Russia), in 2020. Source: Own computations based on Ecoinvent and Ecosense data.

	Norway	Algeria	Russia
2010			
CO_2	2,19E-02	2,16E-02	2,33E-02
CH_4	4,37E-04	1,86E-04	1,95E-04
N_2O	7,31E-03	4,12E-03	4,21E-03
2020			
CO_2	2,36E-02	2,33E-02	2,50E-02
CH_4	3,76E-04	1,60E-04	1,68E-04
N_2O	7,41E-03	4,18E-03	4,26E-03
2030			
CO_2	2,16E-02	2,13E-02	2,30E-02
CH_4	3,36E-04	1,43E-04	1,50E-04
N_2O	6,09E-03	3,43E-03	3,50E-03

Table 5 Unit External Costs [Euro per Ton] GHG emissions from natural gas production offshore (Norway) and onshore (Algeria and Russia), in 2010, 2020 and 2030. Source: Own computations based on Ecoinvent and Ecosense data.

	Base year	*Low Scenario*			*Reference Scenario*			*High Scenario*		
	2004	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***
NMVOC	1,39E-03	1,25E-03	6,42E-04	6,29E-04	1,13E-03	6,07E-04	5,81E-04	1,15E-03	5,98E-04	5,70E-04
NO_X	1,06E-02	1,02E-02	1,10E-02	1,09E-02	9,93E-03	1,07E-02	1,05E-02	1,01E-02	1,06E-02	1,04E-02
PPM^{co}	4,24E-04	4,09E-04	3,59E-04	3,54E-04	3,91E-04	3,46E-04	3,39E-04	3,89E-04	3,43E-04	3,33E-04
PPM^{25}	7,34E-03	7,09E-03	6,86E-03	6,81E-03	6,81E-03	6,72E-03	6,64E-03	6,79E-03	6,68E-03	6,58E-03
SO_2	3,41E-02	3,40E-02	3,61E-02	3,60E-02	3,41E-02	3,59E-02	3,57E-02	3,43E-02	3,59E-02	3,57E-02
CO_2	2,25E-02	2,24E-02	2,40E-02	2,20E-02	2,23E-02	2,39E-02	2,19E-02	2,23E-02	2,39E-02	2,19E-02
CH_4	2,64E-04	2,56E-04	2,07E-04	1,83E-04	2,51E-04	2,02E-04	1,78E-04	2,53E-04	2,01E-04	1,77E-04
N_2O	5,10E-03	5,00E-03	4,86E-03	3,97E-03	4,93E-03	4,80E-03	3,90E-03	4,96E-03	4,78E-03	3,88E-03

Table 6 Averaged Unit External Costs [Euro per Ton] GHG emissions from natural gas, at production. Weights vary with year and scenario.

LNG tankers

Operational externalities from LNG transportation were originally computed on the basis of the LCI assumptions behind the Ecoinvent data for LNG tankers. The implicit assumption there is that LNG tankers are fuelled exclusively with gas. However, Table 3.8 of Technical paper n°2.3 - RS 1c showed that, depending on the type of engines installed on the ship, some LNG tankers can burn also heavy fuel oil, thus generating also SO_2 and particulates emissions. These emission values however could not be directly used in our externality assessment, as they were expressed in emissions per energy consumed. This information could not be translated into emission per ton of LNG transported for 1 Km, without modelling how much energy is required to move one ton of LNG for 1 km along a given route.

To overcome these problems we have resorted to an alternative source of LCI data for ships: the model TEAMS 1.3 developed by the Center for Economic Analysis and Policy, Rochester University, New York.

TEAMS calculates total fuel-cycle emissions and energy use for marine vessels. TEAMS captures emissions along the entire fuel pathway; however it provides emission results for each phase, including ship operation. TEAMS considers six fuel pathways: petroleum to residual oil; petroleum to conventional diesel; petroleum to low-sulphur diesel; natural gas to compressed natural gas; natural gas to Fischer-Tropsch diesel; and soybeans to Biodiesel.

TEAMS calculates total fuel-cycle emissions of three greenhouse gases (carbon dioxide, nitrous oxide, and methane) and five criteria pollutants (volatile organic compounds, carbon monoxide, nitrogen oxides, particulate matter with aerodynamic diameters of 10 micrometers or less (PM_{10}), and sulphur oxides). TEAMS can be used to study emissions from a variety of user-defined vessels, including crude oil and LNG tankers. The operational emissions per ton.Km for a LNG tanker cruising from Ras Tanura to Rotterdam computed on the basis of the TEAMS model output for LNG tankers are presented in Table 7, while externality values are listed in Table 8 (non-GHG emissions in 2010), in Table 9 (non-GHG emissions in 2020) and in Table 10 (GHG emissions in 2010,2020, 2030).

tons/km.ton	Main Engine Fuel:	Auxiliary Engine Fuel:	Total
	Natural Gas	Conventional Diesel	
CO_2	1,35E-06	1,61E-07	1,51E-06
CH_4	7,89E-11	9,55E-12	8,85E-11
N_2O	6,89E-11	4,17E-12	7,31E-11
GHGs	1,38E-06	1,62E-07	1,54E-06
VOC	1,68E-09	2,03E-10	1,88E-09
CO	7,71E-09	9,33E-10	8,64E-09
NO_x	4,23E-08	5,12E-09	4,74E-08
PM^{10}	2,53E-10	3,06E-11	2,84E-10
SO_x	2,41E-10	3,60E-11	2,77E-10

Table 7. Unit emissions from LNG tankers. Source: own computations from TEAMS model output.

	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	Average
			Human Health		
NMVOC	2,44E-07	5,34E-07	1,35E-07	2,99E-07	2,99E-07
NO_X	3,86E-05	7,16E-05	8,86E-05	3,26E-05	4,14E-05
PPM^{co}	6,60E-09	1,82E-08	2,94E-08	2,59E-08	2,06E-08
PPM^{25}	1,12E-07	2,84E-07	4,66E-07	3,82E-07	3,10E-07
SO_2	5,91E-08	1,14E-07	1,89E-07	1,57E-07	1,30E-07
			Loss of Biodiversity		
NMVOC	-1,19E-08	-6,36E-08	-9,04E-09	-1,89E-08	-2,10E-08
NO_X	6,72E-06	3,15E-05	3,46E-06	7,72E-06	9,58E-06
PPM^{co}	0	0	0	0	0
PPM^{25}	0	0	0	0	0
SO_2	1,99E-09	1,079E-08	5,04E-10	1,605E-09	2,5485E-09
			Crops & Material		
NMVOC	7,42E-08	1,973E-07	3,27E-08	8,44E-08	9,00E-08
NO_X	5,14E-06	2,046E-06	2,91E-06	2,32E-06	3,03E-06
PPM^{co}	0	0	0	0	0
PPM^{25}	0	0	0	0	0
SO_2	-9,91E-10	-1,335E-09	-1,848E-10	-7,28E-10	-8,21E-10
			Total		
NMVOC	3,06E-07	6,68E-07	1,59E-07	3,65E-07	3,68E-07
NO_X	5,05E-05	1,05E-04	9,50E-05	4,26E-05	5,40E-05
PPM^{co}	6,60E-09	1,82E-08	2,94E-08	2,59E-08	2,06E-08
PPM^{25}	1,12E-07	2,84E-07	4,66E-07	3,82E-07	3,10E-07
SO_2	6,01E-08	1,23E-07	1,90E-07	1,58E-07	1,32E-07

Table 8 Unit External Costs [Euro per Ton] non- GHG emissions from transport, liquefied natural gas, freight ship in 2010. Source: Own computations based on TEAMS and Ecosense data.

	N.E. Atlantic	Baltic Sea	Black Sea	Mediterranean Sea	Average
Human Health					
NMVOC	1,30E-07	3,18E-07	2,71E-09	1,07E-07	**2,34E-03**
NO_X	5,17E-05	1,21E-04	1,36E-04	6,83E-05	**1,35E+00**
PPM^{co}	5,69E-08	1,58E-07	2,63E-07	2,20E-07	**3,23E-03**
PPM^{25}	9,47E-07	2,40E-06	3,96E-06	3,23E-06	**4,81E-02**
SO_2	7,17E-08	1,52E-07	2,28E-07	1,92E-07	**2,93E-03**
Loss of Biodiversity					
NMVOC	-1,87E-08	-8,27E-08	-1,35E-08	-2,31E-08	**-5,02E-04**
NO_X	9,14E-06	4,30E-05	4,81E-06	1,04E-05	**2,39E-01**
PPM^{co}	0	0	0	0	**0**
PPM^{25}	0	0	0	0	**0**
SO_2	2,55E-09	1,34E-08	6,69E-10	2,19E-09	**6,05E-05**
Crops & Material					
NMVOC	5,07E-08	1,42E-07	2,61E-08	6,81E-08	**1,26E-03**
NO_X	6,09E-06	6,81E-06	3,37E-06	4,32E-06	**9,07E-02**
PPM^{co}	0	0	0	0	**0**
PPM^{25}	0	0	0	0	**0**
SO_2	-9,94E-10	-2,17E-09	-2,46E-10	-1,10E-09	**-2,06E-05**
Total					
NMVOC	1,62E-07	3,77E-07	1,53E-08	1,52E-07	**1,69E-07**
NO_X	6,69E-05	1,71E-04	1,45E-04	8,31E-05	**9,16E-05**
PPM^{co}	5,69E-08	1,58E-07	2,63E-07	2,20E-07	**1,76E-07**
PPM^{25}	9,47E-07	2,40E-06	3,96E-06	3,23E-06	**2,62E-06**
SO_2	7,32E-08	1,63E-07	2,28E-07	1,93E-07	**1,62E-07**

Table 9 Unit External Costs [Euro per Ton] non- GHG emissions from transport, liquefied natural gas, freight ship in 2020. Source: Own computations based on TEAMS and Ecosense data.

	2010	2020	2030
CO_2	9,31E-06	1,00E-05	9,19E-06
CH_4	5,61E-07	4,83E-07	4,32E-07
N_2O	5,23E-07	5,30E-07	4,35E-07

Table 10 Unit External Costs [Euro per Ton] GHG-emissions from transport, liquefied natural gas, freight ship,in 2010, 2020, 2030. Source: Own computations based on TEAMS and Ecosense data.

Pipelines

We take Russian pipelines as representative of pipeline import of natural gas to Europe for externality evaluation purposes. Unit externalities of Russian pipelines, computed for air emissions of greenhouse gasses and of volatile organic compounds under the assumption that Russian pipelines will reach European standards by 2020, are listed in Table 11. Table 12 reports the same externalities under the assumption that Russian technical standards will not improve. These alternative assumptions are considered because, while external cost values appear reasonable for natural gas extraction and LNG, externality values from GHG emissions for natural gas transportation by pipeline, under the assumption that Russian technical standards will not improve, result in relatively high numbers (ranging from 0.05 in 2030 to 0.065 Eurocent per ton in 2010). Although these values are not particularly large in absolute terms, they are still some orders of magnitude higher than other external costs related to gas transport. A reason for this outcome could be that the LCI data from Ecoinvent may refer to below standard, old infrastructures in poor state of maintenance. In the case of gas pipelines, Technical paper n°2.3 - RS 1c showed that GHG emissions from existing Russian pipelines are 1-2 order of magnitudes higher than those from Italian pipelines. Moreover, the Ecoinvent data might have overestimated operational CH_4 emissions by including (part of) accidental emissions. In particular, from Table 3-7 of Technical paper n°2.3 - RS 1c, one can infer[6] that CH_4 emissions from Russian natural gas export corridors to Europe are 21.35 times higher than the Italian ones. Assuming that Russian pipeline standards will be brought close to the Italian ones by current investments in safety and maintenance, the externalities from GHG emissions computed in **Errore. L'origine riferimento non è stata trovata.** can drop, in 2030, to about 2,3E-05 € per ton of natural gas transported.

	2010	2020	2030
CO_2	9,67E-10	1,04E-09	9,55E-10
CH_4	6,47E-04	2,60E-05	2,33E-05
N_2O	0	0	0
NMVOC	7,22E-07	1,66E-08	1,66E-08

Table 11 Unit External Costs [Euro per Ton] for NMVOC and GHG-emissions from transport of natural gas, long distance Russian pipelines, in 2010, 2020 and 2030. Source: Own computations based on Ecoinvent and Ecosense data.

	2010	2020	2030
CO_2	9,67E-10	2,22E-08	2,04E-08
CH_4	6,47E-04	5,56E-04	4,97E-04
N_2O	0	0	0
NMVOC	7,22E-07	3,55E-07	3,55E-07

Table 12 Unit External Costs [Euro per Ton] for NMVOC and GHG-emissions from transport of natural gas, long distance Russian pipelines, in 2010, 2020 and 2030, assuming no improvements in technical standards. Source: Own computations based on Ecoinvent and Ecosense data.

[6] Table 3-7 of Technical paper n°2.3 - RS 1c report total GHG emissions and CO_2 emissions from Russian and Italian networks. Since in the case of natural gas pipeline, CO_2 and methane are the major sources of GHG emission, their difference is roughly attributable to CH_4.

4. External cost evaluation for gas imports to Europe.

The unit externality values described and listed in the previous section give an overall indication of how much external damage is caused by producing a ton of natural gas and by transporting it for one kilometre in the seas around Europe or along a Russian pipeline. However they do not yet give a precise evaluation of how much external cost is generated by *bringing* that ton of gas *into* Europe. More importantly, these values do not allow us to assess what *will be* the evolution of these externality costs in the future.

In order to do that, one needs to combine the unit values of the previous section with an assessment of the flows of natural gas produced for European consumption, and transported to Europe along the main import channels (pipelines and LNG routes) now and in the future. In principle, this can be done with varying degrees of refinement and precision.

In our approach "the future" enters into our analyses as three selected years: 2010, 2020 and 2030. Moreover, we have strived to include as much dynamic elements as possible. In particular, time-dependent parameters and variables in our computations are the following:

- the volumes of natural gas extracted and transported to Europe,
- the routes and the transportation modes used in order to deliver natural gas to European consumers,
- the unit externality values for operational externalities,
- the weights used to compute average operational externalities for the extraction phase,
- the maintenance standards of natural gas pipelines.

Finally, even natural gas flows may vary according to the assumptions one can make about the main drivers that influence international energy markets. In order to at least partially capture some of this particular source of variation, we use three alternative scenarios: a reference scenario, one assuming a lower demand level and one assuming a higher demand level. The main assumptions behind these scenarios are the following[7]:

- Reference Scenario. EU natural gas import requirement is forecast to increase from 267 bcm in 2004 to 364 bcm in 2010, to 530 bcm in 2020 and finally to 606 bcm in 2030. We expect the gas imports via pipelines to remain to be the most important transport mode, even though its share will go down. The volume of imports by pipeline is expected to increase to 407 bcm in 2030, compared to 230 bcm in 2004. NLG imports, on the other hand, will

[7] These scenarios were described in detail in Technical paper n°2.2 - RS 1c: "Present and future natural gas flows and routes from producing areas to Europe", developed by OME, to which the interested Reader is referred to for further details.

increase from 37 bcm in 2004 to almost 200 bcm by the year 2030. Therefore, by 2030 one third of EU gas imports will be in the form of LNG.

- Low Case Scenario. In this scenario, natural gas import need of the EU in 2030 is 176 bcm lower than the reference case scenario. Almost 30% of total import requirement by 2030 (486 bcm) will be satisfied by LNG and the rest 70% by pipeline. While pipeline gas imports will increase from 230 bcm in 2004 to 344 bcm by 2030, a 50% increase over 26 years, LNG imports will almost quadruple and reach 142 bcm in 2030, compared to 37 bcm in 2004.
- High Case Scenario. The EU gas import requirement in high case scenario is slightly more than 10% in 2030 compared to the reference scenario. Two thirds of the increase is satisfied via LNG imports, and the remaining one third via pipelines. Pipeline imports in this scenario increase to 423 bcm in 2030 from 230 bcm in 2004, and LNG imports increase to 240 bcm in 2030 compared with 37 bcm in 2004.

For each of these scenario and for each pollutant, operational externalities along the main import routes and at the most relevant production sites for European gas imports are computed. Their values are then averaged to yield a externality values, for each pollutant, per ton of natural gas produced and per ton of natural gas imported into Europe.

These values are summarised in the Tables below. In particular, Table 13 deals with natural gas extraction, Table 14 and Table 15 deal with natural gas transport (by LNG tanker and by pipeline, respectively), and Table 16 draws the overall externality estimation for the extraction and transport phases of this fuel chain[8].

Finally, in order to allow for the possibility that Russian pipelines may fall to reach European standards in 2020, Table 17 and Table 18 present analogous results, for pipeline and overall external cost respectively, under the assumption that unit emissions from pipelines will remain constant at their 2010 levels.

[8] In the overall external cost assessment, externalities from LNG and from pipeline enter as a weighted average of the two transportation modes, to avoid double counting.

	Base year	Low Scenario			Reference Scenario			High Scenario		
	2004	2010	2020	2030	2010	2020	2030	2010	2020	2030
NMVOC	1,39E-03	1,25E-03	6,42E-04	6,29E-04	1,13E-03	6,07E-04	5,81E-04	1,15E-03	5,98E-04	5,70E-04
NO_X	1,06E-02	1,02E-02	1,10E-02	1,09E-02	9,93E-03	1,07E-02	1,05E-02	1,01E-02	1,06E-02	1,04E-02
PPM^{co}	4,24E-04	4,09E-04	3,59E-04	3,54E-04	3,91E-04	3,46E-04	3,39E-04	3,89E-04	3,43E-04	3,33E-04
PPM^{25}	7,34E-03	7,09E-03	6,86E-03	6,81E-03	6,81E-03	6,72E-03	6,64E-03	6,79E-03	6,68E-03	6,58E-03
SO_2	3,41E-02	3,40E-02	3,61E-02	3,60E-02	3,41E-02	3,59E-02	3,57E-02	3,43E-02	3,59E-02	3,57E-02
CO2	2,25E-02	2,24E-02	2,40E-02	2,20E-02	2,23E-02	2,39E-02	2,19E-02	2,23E-02	2,39E-02	2,19E-02
CH_4	2,64E-04	2,56E-04	2,07E-04	1,83E-04	2,51E-04	2,02E-04	1,78E-04	2,53E-04	2,01E-04	1,77E-04
N_20	5,10E-03	5,00E-03	4,86E-03	3,97E-03	4,93E-03	4,80E-03	3,90E-03	4,96E-03	4,78E-03	3,88E-03
TOTAL	**0,082**	**0,081**	**0,084**	**0,081**	**0,080**	**0,083**	**0,080**	**0,080**	**0,083**	**0,079**

Table 13 External costs (Euro per ton) of natural gas extraction. Base year and projections to 2010, 2020 and 2030 under reference, low demand and high demand scenarios.

	Base year	Low Scenario			Reference Scenario			High Scenario		
	2004	2010	2020	2030	2010	2020	2030	2010	2020	2030
NMVOC	1,50E-03	1,93E-03	1,02E-03	1,08E-03	1,92E-03	1,11E-03	1,20E-03	2,07E-03	1,14E-03	1,23E-03
NO_X	2,20E-01	2,83E-01	5,52E-01	5,89E-01	2,81E-01	6,03E-01	6,51E-01	3,04E-01	6,17E-01	6,67E-01
PPM^{co}	8,38E-05	1,08E-04	1,06E-03	1,13E-03	1,07E-04	1,16E-03	1,25E-03	1,16E-04	1,19E-03	1,28E-03
PPM^{25}	1,26E-03	1,63E-03	1,58E-02	1,69E-02	1,62E-03	1,73E-02	1,86E-02	1,75E-03	1,77E-02	1,91E-02
SO_2	5,39E-04	6,93E-04	9,78E-04	1,04E-03	6,88E-04	1,07E-03	1,15E-03	7,44E-04	1,09E-03	1,18E-03
CO2	3,79E-02	4,88E-02	5,61E-02	5,98E-02	4,85E-02	6,13E-02	6,61E-02	5,24E-02	6,27E-02	6,78E-02
CH_4	2,29E-03	2,94E-03	3,38E-03	3,61E-03	2,92E-03	3,69E-03	3,99E-03	3,16E-03	3,78E-03	4,09E-03
N_20	2,13E-03	2,75E-03	3,15E-03	3,36E-03	2,73E-03	3,44E-03	3,72E-03	2,95E-03	3,53E-03	3,81E-03
TOTAL	**0,27**	**0,34**	**0,63**	**0,68**	**0,34**	**0,69**	**0,75**	**0,37**	**0,71**	**0,77**

Table 14 External costs (Euro per ton) from LNG transport. Base year and projections to 2010, 2020 and 2030 under reference, low demand and high demand scenarios.

	Base year	Low Scenario			Reference Scenario			High Scenario		
	2004	2010	2020	2030	2010	2020	2030	2010	2020	2030
NMVOC	2,07E-03	2,04E-03	4,73E-05	4,71E-05	1,99E-03	4,72E-05	4,64E-05	1,94E-03	4,65E-05	4,62E-05
NO_X	0	0	0	0	0	0	0	0	0	0
PPM^{co}	0	0	0	0	0	0	0	0	0	0
PPM^{25}	0	0	0	0	0	0	0	0	0	0
SO_2	0	0	0	0	0	0	0	0	0	0
CO2	2,77E-06	2,74E-06	2,96E-06	2,71E-06	2,66E-06	2,95E-06	2,66E-06	2,60E-06	2,91E-06	2,65E-06
CH_4	1,85E+00	1,83E+00	7,41E-02	6,60E-02	1,78E+00	7,39E-02	6,50E-02	1,74E+00	7,29E-02	6,48E-02
N_20	0	0	0	0	0	0	0	0	0	0
TOTAL	**1,85**	**1,83**	**0,07**	**0,07**	**1,78**	**0,07**	**0,07**	**1,74**	**0,07**	**0,06**

Table 15 External costs (Euro per ton) from pipeline transport of natural gas. Base year and projections to 2010, 2020 and 2030 under reference, low demand and high demand scenarios.

	Base year	*Low Scenario*			*Reference Scenario*			*High Scenario*		
	2004	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***
NMVOC	3,37E-03	3,27E-03	9,67E-04	9,79E-04	3,10E-03	9,88E-04	1,01E-03	3,13E-03	1,01E-03	1,04E-03
NO_X	4,10E-02	6,64E-02	1,70E-01	1,83E-01	8,43E-02	2,00E-01	2,24E-01	9,11E-02	2,18E-01	2,52E-01
PPM^{co}	4,36E-04	4,30E-04	6,63E-04	6,85E-04	4,20E-04	7,11E-04	7,50E-04	4,20E-04	7,41E-04	7,97E-04
PPM^{25}	7,51E-03	7,41E-03	1,14E-02	1,17E-02	7,24E-03	1,22E-02	1,28E-02	7,26E-03	1,26E-02	1,35E-02
SO_2	3,42E-02	3,41E-02	3,63E-02	3,63E-02	3,43E-02	3,62E-02	3,61E-02	3,45E-02	3,62E-02	3,61E-02
CO2	2,77E-02	3,21E-02	4,01E-02	3,95E-02	3,51E-02	4,32E-02	4,36E-02	3,63E-02	4,50E-02	4,64E-02
CH_4	1,59E+00	1,47E+00	5,40E-02	4,80E-02	1,31E+00	5,20E-02	4,52E-02	1,28E+00	4,99E-02	4,30E-02
N_20	5,40E-03	5,54E-03	5,77E-03	4,96E-03	5,65E-03	5,88E-03	5,12E-03	5,75E-03	5,97E-03	5,26E-03
TOTAL	**1,71**	**1,62**	**0,32**	**0,32**	**1,48**	**0,35**	**0,37**	**1,46**	**0,37**	**0,40**

Table 16 Overall external costs (Euro per ton) from natural gas extraction and transport. Base year and projections to 2010, 2020 and 2030 under reference, low demand and high demand scenarios.

	Base year	*Low Scenario*			*Reference Scenario*			*High Scenario*		
	2004	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***
NMVOC	2,07E-03	2,04E-03	1,01E-03	1,01E-03	1,99E-03	1,01E-03	9,91E-04	1,94E-03	9,94E-04	9,87E-04
NO_X	0	0	0	0	0	0	0	0	0	0
PPM^{co}	0	0	0	0	0	0	0	0	0	0
PPM^{25}	0	0	0	0	0	0	0	0	0	0
SO_2	0	0	0	0	0	0	0	0	0	0
CO2	2,77E-06	2,74E-06	6,33E-05	5,78E-05	2,66E-06	6,30E-05	5,69E-05	2,60E-06	6,22E-05	5,67E-05
CH_4	1,85E+00	1,83E+00	1,58E+00	1,41E+00	1,78E+00	1,58E+00	1,39E+00	1,74E+00	1,56E+00	1,38E+00
N_20	0	0	0	0	0	0	0	0	0	0
TOTAL	**1,85**	**1,83**	**1,58**	**1,41**	**1,78**	**1,58**	**1,39**	**1,74**	**1,56**	**1,38**

Table 17 External cost (Euro per ton) from pipeline transport of natural gas. Base year and projections to 2010, 2020 and 2030 under reference, low demand and high demand scenarios, assuming no improvement in technical standards.

	Base year	*Low Scenario*			*Reference Scenario*			*High Scenario*		
	2004	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***	***2010***	***2020***	***2030***
NMVOC	3,37E-03	3,27E-03	1,65E-03	1,66E-03	3,10E-03	1,65E-03	1,64E-03	3,13E-03	1,64E-03	1,64E-03
NO_X	4,10E-02	6,64E-02	1,70E-01	1,83E-01	8,43E-02	2,00E-01	2,24E-01	9,11E-02	2,18E-01	2,52E-01
PPM^{co}	4,36E-04	4,30E-04	6,63E-04	6,85E-04	4,20E-04	7,11E-04	7,50E-04	4,20E-04	7,41E-04	7,97E-04
PPM^{25}	7,51E-03	7,41E-03	1,14E-02	1,17E-02	7,24E-03	1,22E-02	1,28E-02	7,26E-03	1,26E-02	1,35E-02
SO_2	3,42E-02	3,41E-02	3,63E-02	3,63E-02	3,43E-02	3,62E-02	3,61E-02	3,45E-02	3,62E-02	3,61E-02
CO2	2,77E-02	3,21E-02	4,01E-02	3,95E-02	3,51E-02	4,33E-02	4,37E-02	3,63E-02	4,50E-02	4,64E-02
CH_4	1,59E+00	1,47E+00	1,13E+00	9,99E-01	1,31E+00	1,08E+00	9,34E-01	1,28E+00	1,03E+00	8,84E-01
N_20	5,40E-03	5,54E-03	5,77E-03	4,96E-03	5,65E-03	5,88E-03	5,12E-03	5,75E-03	5,97E-03	5,26E-03
TOTAL	**1,71**	**1,62**	**1,39**	**1,28**	**1,48**	**1,38**	**1,26**	**1,46**	**1,35**	**1,24**

Table 18 Overall external costs (Euro per ton) from natural gas extraction and transport. Base year and projections to 2010, 2020 and 2030 under reference, low demand and high demand scenarios, assuming no improvement in technical standards.

It can be noticed that external damages are quite low, for each time horizon considered and for each scenario. This is mainly due to the chemical characteristics of natural gas, whose content of most local pollutants is negligible, and the fact that the main fuel used to generate the energy necessary to produce and transport natural gas is natural gas. It can also be noticed that externality values are markedly declining over time. Comparing Table 15 with Table 17 and Table 16 with Table 18, one observes that this is manly due to our assumption of improving technical standards in the Russian pipelines, which we assume in Table 15 and Table 16 will result in emissions levels in 2020 and 2030 analogous to those currently occurring in Western Europe.

Note however that, in general, most externality values decline slightly over time, also under the assumption of no technical improvement in Russian pipelines. This is “residual” decline is due to the underlying assumption behind Ecosense’s externality values: negative impacts and GHG marginal costs become less substantial over time.

5. Concluding Remarks

No economic activity is immune from causing negative external effect, and the natural gas sector is no exception. However, compared to other fossil fuels, coal and oil in particular, the externalities generated are far less worrying. This holds for operational externalities as well as for probabilistic externalities. Although standards of existing installations are not homogenous across the world and some exporting regions still need to catch up with European standards (a typical example are Russian vs. European pipelines) recent trends show that gaps are closing. Particularly high standards are applied in the downstream section of the LNG chain, while the upstream section seem to be characterized by low risks, although a few accidents have happened, one of which (Skikda) with serious consequences, and information is not very transparent and readily available.

The incompleteness of available information prevented us from reaching a complete assessment of probabilistic externalities in this sector. However the available data and information seem to suggest that the magnitude of probabilistic externalities in the natural gas chain is likely to be very small.
It should be noted that dealing with natural gas is in theory a very risky business: due to its chemical and physical properties, it may generate, in well known circumstances, flammable and explosive mixtures. However, safety standards are such that these risks are nowadays extremely low and constantly diminishing. Moreover, in most circumstances, accidents are likely to involve almost exclusively workers in the natural gas industry, whose exposure to probabilistic externalities should be, to a large extent, internalized in their contracts.

Operational externalities are present, but again, being the sulphur and particulate content of natural gas negligible, their importance in terms of impacts human health, biodiversity and human activities is much lower than for other fossil fuel. GHG-related externalities are more substantial, especially where fugitive emissions of natural gas are high, as it is still the case along the Russian pipelines; however the current trend of improving standards prompt hopes that also these impacts will be substantially reduced in the coming years.
Indeed, the main conclusion of this assessment is that externalities related to the natural gas chain are not negligible, but still relatively quite small, and slightly declining in the coming decades. This conclusion stems from an in-deep assessment of operational externalities related to the extraction of natural gas for European consumption and to its transportation to Europe, which has been performed on the basis of natural gas demand and import flows scenarios developed by OME, and has generated overall externality values which range between 0.32 Euro per ton of natural gas

transported to Europe in 2020 in the Low demand scenario and 1.71 Euro per ton of natural gas transported to Europe in the base year (2004).

References

[1] Abu Dhabi Gas Liquefaction Company (2004): “HSE Annual Report”

[2] Avidan A., Messersmith D., Martinez B. (2002): “LNG Liquefaction technologies move toward greater efficiencies, lower emissions”, Oil & Gas Journal

[3] Avidan A., Richardson F., Anderson K., Woodard B. (2001): “LNG Plant scale-up can cut costs further”, Petroleum Economist fundamentals of the LNG Industry

[4] Awchuk J., Jones R., Ward P. (2002): “BP Big Green train - The next generation in LNG”, Gastech 2002

[5] Bigano, A , Cassinelli, M., Markandya, M., Sferra, F. “Gas Transportation: Burdens and Impacts.” NEEDS Technical Paper n° 2.3 - RS 1c, www.needs-project.org

[6] Bykov A., Uliyanov I. “Official Energy Statistics in the Russian Federation”, Federal State Statistics Service (Rosstat)

[7] CE Delft, Germanischer Lloyd, MARINTEK and Det Norske Veritas (2006): “Greenhouse Gas Emissions for Shipping and Implementation Guidance for the Marine Fuel Sulphur Directive”

[8] Cooke R.M., Jager E., Lewandowski D. (2002): “Reliability Model for Underground Gas Pipelines”

[9] ENI Gas & Power (2004): “Rapporto Sicurezza Ambiente, Rapporto 2004”

[10] Environmental International Agency documents and databases

[11] Environmental Protection Agency, Gazprom (1996): “Methane Leak Measurements and Selected Natural Gas Pipeline Compressor Stations in Russia”

[12] Environmental Protection Agency, Gazprom (1998): “Opportunities for Reducing Methane Emissions from the Russian Natural Gas System”

[13] Environmental Protection Agency (2001): “Reducing GHG Emissions Through International Technology Transfer”

[14] Eurostat

[15] Federal/Provincial/Territorial Committee on Environmental and Occupational Health (2004): “Canadian Handbook on Health Impact Assessment - Volume 4: Health Impacts By Industry Sector”

[16] Foss M.M (2003): “LNG Safety and Security”, Centre for Energy Economics

[17] Hayes M. H. (2004): “Algerian Gas to Europe: The Transmed Pipeline and Early Spanish Gas Import Projects”, Working Paper #27

[18] Hightower M., Gritzo L., Luketa-Hanlin A., Covan J., Tieszen S., Wellman G., Irwin M., Kaneshige M., Melof B., Morrow C., Ragland D. (2004): “Guidance on Risk Analysis and Safety Implications of a Large Liquefied Natural Gas (LNG) Spill Over Water”, SAND2004-6258, Sandia

[19] International Finance Corporation (2007): “Environmental, Health, and Safety Guidelines”

[20] Pacific Northwest National Laboratory (2001):”Estimating Methane Emissions From the Russian Natural Gas Sector”

[21] Sakhalin Energy Investment Company Ltd.: “Project Alternatives Liquefied Natural Gas Plant / Oil Export Terminal Site Selection Report”

[22] Wikipedia: “Liquified Natural Gas”

[23] Wuppertal Institute (2004) :”Calculations according to internal data of Gazprom/VNIIGaz”

[24] Wuppertal and Mainz (2005): “Greenhouse gas emissions from the Russian Natural Gas Export Pipeline System”

[25] http://www.capitallinkrussia.com/companies/50010088/

[26] EIA, http://www.eia.doe.gov/emeu/cabs/algeria.html , 30/3/2007

[27] ENI spa, http://specials.eni.it/italiano/bilancio_2004_it/pagina_3/pag_3_1_di5_s1.htm, visited on 30/3/2007

[28] ENI spa, http://www.eni.it/eni/internal.do?RID=@2BUBe%7C0?xoidcmWopk&catId=-1073756928&cntTypeId=1005&portalId=0&lang=it&sessionId=15506708, visited on 30/3/2007

[29] ENI spa, http://www.eni.it/eni/internal.do?RID=@2BU4Q%7C0?xoidcmWopk&catId=-1073756927&cntTypeId=1005&portalId=0&lang=it&sessionId=15567665, visited on 30/3/2007

[30] http://www.gazprom.com/documents/Annual_Report_Eng_2005.pdf

[31] Karbuz, S, Elandaloussi, H., Hafner, M.: “Present and future natural gas flows and routes from producing areas to Europe”, NEEDS Technical paper n°2.2 - RS 1c, www.needs-project.org

[32] Oilvoice, http://www.oilvoice.com/m/viewEd.asp?ed_ID=16 , visited on 30/3/2007

[33] http://planetforlife.com/gascrisis/gaspolitics.html

[34] Preiss, Philipp (2007) "Report on marginal external costs – Preliminary results" NEEDS Technical Paper n° 1.4 - RS 3a, www.needs-project.org.

[35] Wikipedia, http://en.wikipedia.org/wiki/GALSI, 30/3/2007

[36] Wikipedia, http://en.wikipedia.org/wiki/Greenstream_pipeline, visited on 30/3/2007

[37] http://www.rainews24.it/Notizia.asp?NewsId=71878