IS NATURAL GAS A FRIEND OF THE CLIMATE?

Analysis of emissions related to the gas supply chain to the European Union and Barcelona.

ODG
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Contents

1. Introduction: What is natural gas?

The general objective of this study is to evaluate the climate impacts of the gas supply chain: in particular, those associated with liquefied natural gas (LNG) transits arriving in the European Union and the port of Barcelona.

Over recent years, several international organisations including the European Commission have promoted natural gas, portraying it as a useful transition fuel due to its low combustion emissions. However, this support for natural gas is not supported by a rigorous and independent assessment of its climate impact.

Taking into account that the greenhouse effect of methane (the principal component of natural gas) is 86 times that of CO_2, it is clear that methane leakages between extraction and consumption need to be taken very seriously. Renowned scientists including Robert Howarth (Cornell University) contend that in many cases emissions related to natural gas are higher than those related to an equivalent amount of coal.

In the case of LNG, the gas undergoes a complex liquefaction operation at the departure port and is then transported by a carrier, arriving at its destination in a liquid state. This reduces its volume 600-fold, making transits more cost effective. The European cities with facilities to receive LNG carriers are: Bruges (Belgium); Barcelona, Bilbao, Cartagena, Ferrol, Huelva and Sagunto (Spain); Dunkirk, Martigues and Nantes (France); Megara (Greece); Livorno, La Spezia and Venice (Italy); Gargždai (Lithuania); Rotterdam (The Netherlands); Szscecin (Poland); Setubal (Portugal); Haverfordwest and London (United Kingdom) and Aliaga and Çorlu (Turkey).

The Port of Barcelona has one of the most significant regasification plants in both Spain and the European Union, representing 24.67% and 8.18% of total Spanish and European capacity respectively. In 2016, it received 44 transits coming from Nigeria, Algeria, Qatar, Norway and Peru.

From a climate perspective, it is important to analyse what the entry of the US into the export market alongside traditional exporters might mean. The extraction of unconventional gas through fracking increases methane emissions into the atmosphere dramatically. Taking this into consideration, this study quantifies emissions caused by the gas supply chain from US to Europe.

2. Methodology

There is currently a lack of consensus regarding methodologies for determining how much methane leakage occurs in each part of the natural gas supply chain and where it comes from.

For this reason, this study has drawn on 11 scientific research papers to identify factors affecting emissions during each part of the natural gas supply chain. Furthermore, another five papers have been used to estimate the methane leak percentage above which natural gas would have a larger climate impact than coal.

Data regarding LNG carrier transits imported by the European Union in 2016 was provided by ICIS LNG Edge[1]. The Global LNG Info[2] database was used to determine the characteristics of LNG carriers, and data from the BP Port to Port[3] program was used to estimate the optimum transit time for each transit.

In this study, three emissions totals are reported based on transit type (imports to the European Union, imports to Barcelona and exports from the US). Emissions produced in transit have been calculated taking into account the difference in LNG volume between the departure port and the destination port and the emission factor corresponding to burning the gas, in addition to methane leakages occurring in the supply chain prior to liquefaction.

More detailed information on the methodology can be found in the academic work available at the following link:

http://upcommons.upc.edu/handle/2117/110933

1 ICIS LNG Edge: www.icis.com/press-releases/lng-edge-launch/
2 Global LNG Info: www.globallnginfo.com/GLNG_Database.aspx
3 BP Port to Port: https://softadvice.informer.com/Bp_Distance_Port_To_Port.html

3. General characteristics of natural gas

3.1. Biophysical properties

Natural gas is the only fossil fuel which exists in a gaseous state in nature. It is extracted from gas reservoirs or extracted as a by-product of oil extraction. It is mostly made up of methane, between 87% and 97%, and also contains other hydrocarbons such as ethane, propane or butane along with other substances including nitrogen and CO_2 (Perez 2017).

Methane has a lifespan of 12 years in the atmosphere, while CO_2 lasts more than 100 years (Howarth 2014). Therefore, it is difficult to compare the two main contributors to climate change on the same timescale.

Natural gas is colourless and, contrary to what many people think, odourless, although an odorant substance is added to facilitate leak detection. Natural gas is not toxic, but can displace oxygen and kill by suffocation (Perez 2017).

Natural gas can be categorised by location and extraction technique. Although there are no international standardised criteria for differentiating "conventional" and "unconventional" natural gas (Cremonese & Gusev 2016), in general we call natural gas found in accessible reservoirs "conventional" gas, since the technique used to extract it has been used since gas extraction began. "Unconventional" gas, however, is found in more unfavourable locations and more sophisticated and aggressive techniques are required to extract it, such as hydraulic fracturing or fracking.

What is natural about "natural gas?"

Referring to a gas that is primarily methane as "natural" can lead to misunderstandings. The name comes from its extraction from the natural environment, unlike gas manufactured from coal or oil, which is known as "town gas". However, the gas industry has linked the term "natural" with a green, low emissions future, and so many critics prefer the term "fossil gas", since this best describes the source of the fuel and its climate impacts (Pérez 2017). In this report, from now on, it will be simply referred to as "gas".

3.2. Global Warming Potential (GWP)

Global Warming Potential (GWP) is based on the radiative impact and lifespan of gas in the atmosphere, including the direct radiative effects of the gas itself, time of emission, and the indirect radiative effects produced through interactions with other atmospheric components. The current Intergovernmental Panel on Climate Change (IPCC) definition of GWP is very limited because it does not account for indirect radiative effects; however, it is important to take these into consideration, because its greenhouse effect is enhanced when it react with other atmospheric constituents, such as aerosols (Shindell et al. 2009).

Timescales are an important consideration when quantifying GWP. The timescales used in IPCC reports span 10, 20, 100 and 500 years. The most widely used in the political sphere is 100 years, since international treaties have established its use as a standard value to facilitate decision-making (Howarth et al. 2012). When it comes to shorter time spans, 10 or 20 years, it is more difficult to estimate GWP since it is dependent on when the emissions were produced (Shindell et al. 2009).

Despite what has been decided in international treaties, the 5th IPCC report[4] states that "there is no scientific argument that backs the decision to choose the timescale of 100 years for comparing different greenhouse gases (GHGs)" and that "selection of the time spans depends on the relative weights assigned to the various effects and which impact assessment we wish to make based on the analysis". The existing discussion regarding selection of timescales occurs because some of the actors involved want to emphasize the climate effects that can occur in the short term (over the next 20 years), which may be the most appropriate regarding the lifespan of methane in the atmosphere, while others believe it is more important to evaluate climate dynamics produced in the long term (over hundreds of years), where CO_2 would be the major contributor (Sanchez & Mays 2015).

Given that the lifespan of methane is 12 years in the atmosphere, it is believed that the most suitable scale to assess its contribution to global warming would be a 20 year period. The 4th[5] and 5th IPCC reports have quantified the GWP of methane for this timescale at 72 and 86 respectively, whilst the value determined by the study by Shindell et al. (2009) is 79 considering the direct radiative effects only and 105 considering both direct and indirect effects.

4 IPCC (2013): www.climatechange2013.org/images/report/WG1AR5_ALL_FINAL.pdf
5 IPCC (2007): www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf

3.3. Gas vs. coal

Gas is being advocated as a useful fuel for supporting renewable energies and as a substitute for coal, since it has the lowest CO_2, emissions on combustion of existing fossil fuels (see table 1).

Fuel	CO_2 /MMBtu (Millions Btu)	% in relation to gas
Gas	**117**	
Propane	139	119%
Gasoline	157.2	134%
Diesel fuel and heating oil	161.3	138%
Coal (subbituminous)	214.3	183%
Coal (lignite)	205.7	176%
Coal (bituminous)	215.4	184%
Coal (Anthracite)	228.6	195%

Table 1: Emission factors for various fossil fuels and derivatives during combustion. (Source: (Pérez 2017))

However, studies by the Environmental Defence Fund (EDF) show that if the amount of methane leakage in the various operations comprising the gas supply chain is superior to 2.7% of the original gas volume there is no climate benefit compared to coal (Cremonese & Gusev 2016). This is called the "coal threshold value".

The study by Alvarez et al. (2012) calculates this value to be 3.2%. The values estimated by Howarth (2014) and Sanchez & Mays (2015) are 2.8% and 3.7-3.9% respectively. The International Energy Agency (IEA), a reference institution in the field of energy, has set this value at 3% in its World Energy Outlook (WEO) 2017[6]. All studies and reports considered leakage from gas extraction to combustion for electricity generation and used the timescale of 20 years.

Study	% leakage
Alvarez et al. 2012	3.2%
Howarth 2014	2.8%
Sánchez & Mays 2015	3.7%–3.9%
Cremonese & Gusev 2016	2.7%
IEA 2017	3%

Table 2: Percentage of leakage at which gas ceases to have a climate benefit compared to coal, assuming it is used for electricity generation.

6 World Energy Outlook 2017: http://www.iea.org/bookshop/750-World_Energy_Outlook_2017

4. Emission factors throughout the gas supply chain

4.1. Definition and classification of stages and operations

One of the objectives of this report is to determine the climate impact of methane leakages which occur throughout the gas supply chain. To do this, 11 scientific papers have been evaluated to identify the emission factors related to each part of the supply chain.

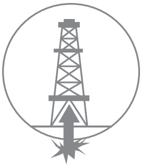
The gas supply chain has three stages: upstream, midstream and downstream. Each one includes different operations. This report includes the impact of well abandonment due to the fact that gas leakage can continue once the well has been abandoned.

It should be noted that there are no generalised criteria available to separate these operations. Therefore, the operations in the studies evaluated are not easily comparable. Moreover, many of the studies define gas production as a different operation to that of gas extraction and its subsequent phases. This report does not consider gas production as a separate operation to extraction due to the fact that gas is a natural resource and not a product; the processes which must be carried out to make it ready for transportation and use are minimal.

The estimation of emission factors in the various operations of the gas supply chain can be done using two different methodologies, bottom-up or top-down. The bottom-up methodology involves measuring the methane emissions generated by a particular component and then multiplying that by the number of those components found in the study area. On the other hand, studies which use the top-down methodology estimate the amount of methane emissions caused the gas industry using the concentration of methane found in the atmosphere, measured using satellites, planes, towers or land vehicles. Studies by agencies such as the United States Environmental Protection Agency (EPA) or by the gas industry are often calculated using the bottom-up methodology whilst scientific field studies tend to be carried out using the top-down methodology.

To compare the emission factors related to each of the operations across the studies, a summary table has been made which includes the classification of the operations and stages (see table 4). Each row of the table represents a study (11 in total). The columns show the operations in the gas supply chain.

Upstream



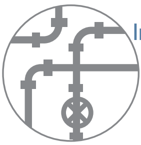
Drill-out — Drilling and channelling activities in order to access the reservoir

Flowback — Operation specific to fracking (unconventional gas) where water is pumped underground in order to extract gas

Extraction — Exploitation of the reservoir to obtain gas

Liquid unloading — Separation of gas from liquids, such as water

Midstream



Internal pipeline transport — Transport of extracted gas to a local processing plant within the field or extraction zone

Downstream

Gas processing — Removal of impurities which can cause corrosion problems during pipeline transport and the injection of the gas into the transmission pipeline

Transmission — Pipeline transport and treatment in the gas compression station from the field to the distribution or liquefaction plant

Storage — Gas storage in the tankers of the distribution, liquefaction or regasification plant

Distribution — Transport of gas from the distribution or regasification plant to the consumer

4.2. Current limitations and constraints

The industry determines in which installations methane leakages occurring in different components and devices can be measured (Caulton et al. 2014). This makes it very difficult to obtain independent and objective results, limits the size and representativeness of the sample and tends to underestimate the values of emission factors in various operations. The solution would be to measure and monitor these factors independently and not through a prior agreement with the industry itself (Karion et al. 2013).

The majority of publications which analyse methane emissions worldwide show that very few emission factors have been verified by empirical research. To reduce the uncertainty surrounding methane leakages along the gas supply chain, it is necessary to carry out direct measurements globally.

Particular emphasis should also be placed on oil and gas extraction and the activities and processes involved since the majority of methane leakages occur during this operation, whether burned or left to escape. This is because the pipelines do not have the capacity to receive all of the extracted gas or due to prohibitive costs (Schneising et al. 2014). Leakages which happen during extraction and in gas processing mainly happen in valves and compressors, as a result of uncontrolled releases during routine operations (of pneumatic devices), or during periodic maintenance operations (Marchese et al. 2015).

Table 4: Summary table comparing emission factors determined in each operation, differentiating between studies that considered the bottom-up and top-down methodology. The rows represent the 11 studies analysed and columns the gas supply chain operations defined in this report

<table>
<tr><th></th><th colspan="10">Stages</th></tr>
<tr><th></th><th colspan="4">Upstream</th><th>Midstream</th><th colspan="4">Downstream</th><th rowspan="2">Well abandonment</th></tr>
<tr><th></th><th>Drill-out</th><th>Flowback</th><th>Extraction</th><th>Liquid unloading</th><th>Pipeline transport</th><th>Gas processing</th><th>Transmission</th><th>Storage</th><th>Distribution</th></tr>
<tr><td>Howarth et al. 2011</td><td>Conv. -> 0.01%
Unconv. -> 0.33%
(0.62% Wood et al. 2011)</td><td>Conv. -> 0%
Unconv. -> 1.6%</td><td>0.3% - 1.9%</td><td>0% - 0,26%</td><td></td><td>0% - 0.19%</td><td colspan="3">1.4% - 3.6%</td><td></td></tr>
<tr><td>Venkatesh et al. 2011</td><td></td><td></td><td colspan="7">1.5 - 3.2% (2.2%)</td><td></td></tr>
<tr><td>Howarth et al. 2012</td><td colspan="6">1.70%</td><td colspan="3">0.9%</td><td></td></tr>
<tr><td>Karion et al. 2012</td><td></td><td></td><td colspan="4">6.2% - 11.7%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Allen et al. 2013</td><td></td><td colspan="3">0.42%</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Brandt et al. 2013</td><td></td><td>0 % - 0.26%</td><td colspan="4">0.1% - 2.35% (1%)</td><td></td><td></td><td>0% - 0.8% (0.15 %)</td><td>0 % - 1% (0.08 %)</td></tr>
<tr><td>Caulton et al. 2014</td><td>7%</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Petron et al. 2014</td><td></td><td></td><td colspan="4">2.6% - 5.6% (4.1%)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Schneising et al. 2014</td><td colspan="6">Bakken --> 2.8% - 17.4% (10.1%) & Eagle Ford --> 2.9% - 15.3% (9.1%)</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Marchese et al. 2015</td><td></td><td></td><td colspan="4">0.47%</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Höglund- Issakson 2017</td><td></td><td></td><td colspan="4">Conv. --> 0.03% - 0.72% (0.52%)
Unconv. --> 0.57% - 5%</td><td></td><td></td><td></td><td></td></tr>
</table>

Indications

0.1 % - 2.35 % (1%): Minimum value - Maximum value (Median)

Conv.: Conventional gas extraction

Unconv.: Unconventional gas extraction

Bakken and Eagle Ford: Unconventional gas fields in the United States

Top-down

Bottom-up

The fundamental and variable benchmarks of the US Environmental Protection Agency (EPA)

Despite being a national organisation, the US EPA is one of the major global references for emission factors along the gas supply chain.

In 2009, EPA still did not differentiate between conventional and unconventional gas. It used values to estimate methane leakages from a study carried out in 1996 in collaboration with the industry itself[7] (Howarth 2014).

At the beginning of 2010, EPA made a distinction between conventional and unconventional gas for the first time. For conventional gas the emission factor value for the upstream stage was changed from 0.2% to 1.6%. For unconventional gas it was changed from 0.2% to 3.0%. Emission factor values for the downstream stage were kept at 0.9% (Howarth 2014). It must be acknowledged that a study carried out by Dlugokencky (2003) showed higher values in the downstream stage in Europe.

In 2013 EPA reduced the emission factor value for the upstream stage based on a report carried out by the industry[8]. The report considered methane leakages resulting from liquid unloading to be negligible and claimed that losses occurring during refracturing were lower than when the well was fractured for the first time (Howarth 2014).

In 2015 EPA took a step to reduce the amount of methane emissions resulting from well construction through the use of techniques for capturing methane leakages produced during this operation. This was done in response to the results presented in the study by Howarth (2014) and criticism of the 2013 update of the emission factors.

7 US Environmental Protection Agency (1996): www.epa.gov/sites/production/files/2016-08/docu%ADments/1_executiveummary.pdf

8 Americcan Petroleum Institute (2012): www.api.org/~/media/Files/News/2012/12-October/API-ANGA-Survey-Report.pdf

5. Properties of LNG

To transform gas from a gaseous state into liquid state, it must go through a cryogenic process at approximately -160˚C during which its volume is reduced more than 600-fold. The composition of LNG depends directly on the characteristics of the gas extracted from the well and the pre-treatment and liquefaction process carried out in the liquefaction plant itself (see table 5). In some cases the requirements of the consumer and its end purpose can also have an influence.

Boiling point	Density	Gross calorific value
from -160°C to -162°C	from 425 kg/m^3 to 485 kg/m^3	from 6333 kWh/m^3 to 7333 kWh/m^3

Table 5: Thermo-physical properties of LNG. (Source: Dobrota et al. (2013))

LNG can be used for power generation, residential and industrial uses, gas storage for peak demand and as a fuel source for heavy maritime transport (including LNG carriers themselves), and road and rail transport.

The LNG supply chain is made up of the following stages (API 2015): gas treatment, gas liquefaction, LNG transport, storage and regasification.

Boil-Off Gas (BOG) and emissions associated with LNG

Boil-off gas (BOG) is generated when LNG evaporates, due to heat exchange with the exterior. The main contributing factor is outside temperature. BOG is mainly composed of methane and nitrogen as these are the components of LNG which evaporate first. BOG is used as a fuel source although it can also be re-liquefied depending on the type of LNG carrier. The majority of BOG is generated during LNG transport by carrier, in a quantity of between 0.10% and 0.15% of the volume transported per day. This is calculated for the most efficient technology available. For gas storage tanks the ratio is less than 0.05% of the total volume contained in the storage tank per day although it can vary between 0.02% and 0.10% (Dobrota et al. 2013). The energy consumed by the cryogenic process is 0.81 kWh/kg of LNG. The majority is released as heat (approximately 70%) and the rest is called "cold energy" which is stored in LNG and released during the regasification process (Franco & Casarosa 2014).

The excess BOG can be burned off using a mechanism called Gas Combustion Unit. When the carrier is moored in port, BOG is released directly into the atmosphere as it is prohibited to burn it off within port premises for safety reasons (Browman & Briers 2009). This method of managing BOG has a more significant climate impact than using a Gas Combustion Unit due to the fact that BOG is practically 100% methane.

6. Characteristics and classification of LNG carriers

A particular characteristic of LNG carriers is that the tank requires special materials and advanced technology to keep the gas cryopreserved. Although the configuration of the tanks can be different, the rest of the elements making up the carrier's structure are the same (see figure 1).

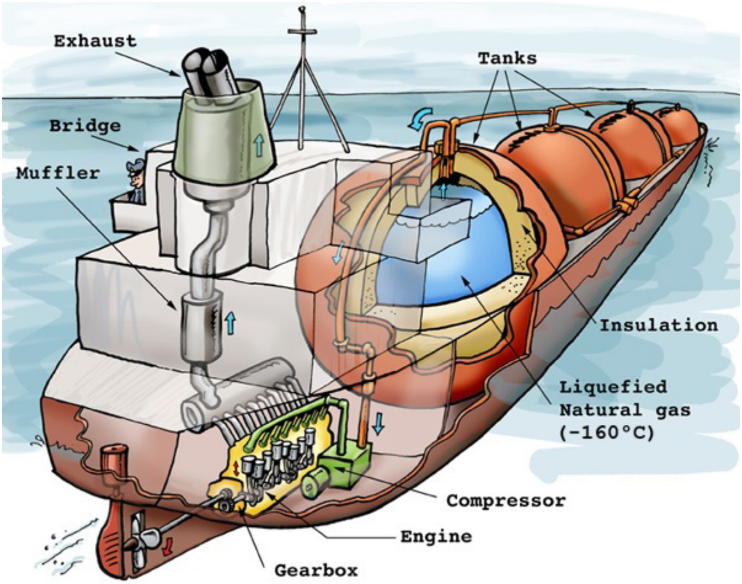


Figure 1: Diagram of LNG carrier's structure (Source: API (2015))

LNG carriers are classified according to the volume of LNG which they can transport. The different types of LNG carriers are: small, small conventional, large conventional, Q-Flex and Q-Max. Figure 2 shows the characteristics of each type.

Small conventional were the most common LNG carriers until the mid-2000s when technological advances allowed large conventional carriers to do transits as quickly as small conventional carriers. Moreover, they have a larger capacity.

Figure 2: Capacities and characteristics of each type of LNG carrier

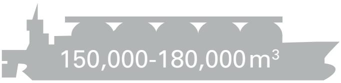
Small

Often used for short transits, giving flexibility to the LNG market as they can cope with unfavourable situations to satisfy consumer demand.

Small conventional

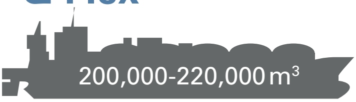
An optimal balance between transporting large volumes and completing transits in a reasonable time.

Large conventional

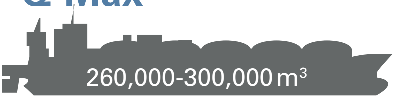


Technological advances during the last decade have given this LNG carrier the same characteristics as the small conventional, but a larger capacity.

Q-Flex



Q-Max



These are the only carriers with built-in reliquefaction plants to return BOG to a liquid state. This keeps losses to a minimum during the transits, important as they are often very large. The other carriers often use BOG as a fuel source.

7. Description of the European LNG market and associated emissions

7.1. Characterisation

In 2016, the European LNG market has seen exchanges between nine exporting countries and eleven importing countries (including Turkey). The world map of the European LNG market for 2016 (see pages 16 and 17) illustrates the interrelations between countries in the supply chain.

7.2. Results

Ports in the European Union received 664 transits during the year 2016. The estimation of emissions for each operation was made using the ranges of emission factors established in the study by Howarth et al. (2011), except those that correspond to the LNG supply chain, which were estimated using the calculated methods outlined in this report. The capacity of the LNG carrier for each of the countries corresponds to the carrier making most transits to European ports during the year 2016.

Country of origin	Capacity of LNG carrier(m^3)	Emissions(tCO_2eq)	
Qatar	148,786	Min.	120,045
		Max.	361,996
Algeria	75,500	Min.	61,100
		Max.	179,583
Nigeria	160,000	Min.	130,975
		Max.	382,067
Norway	140,000	Min.	114,664
		Max.	349,453

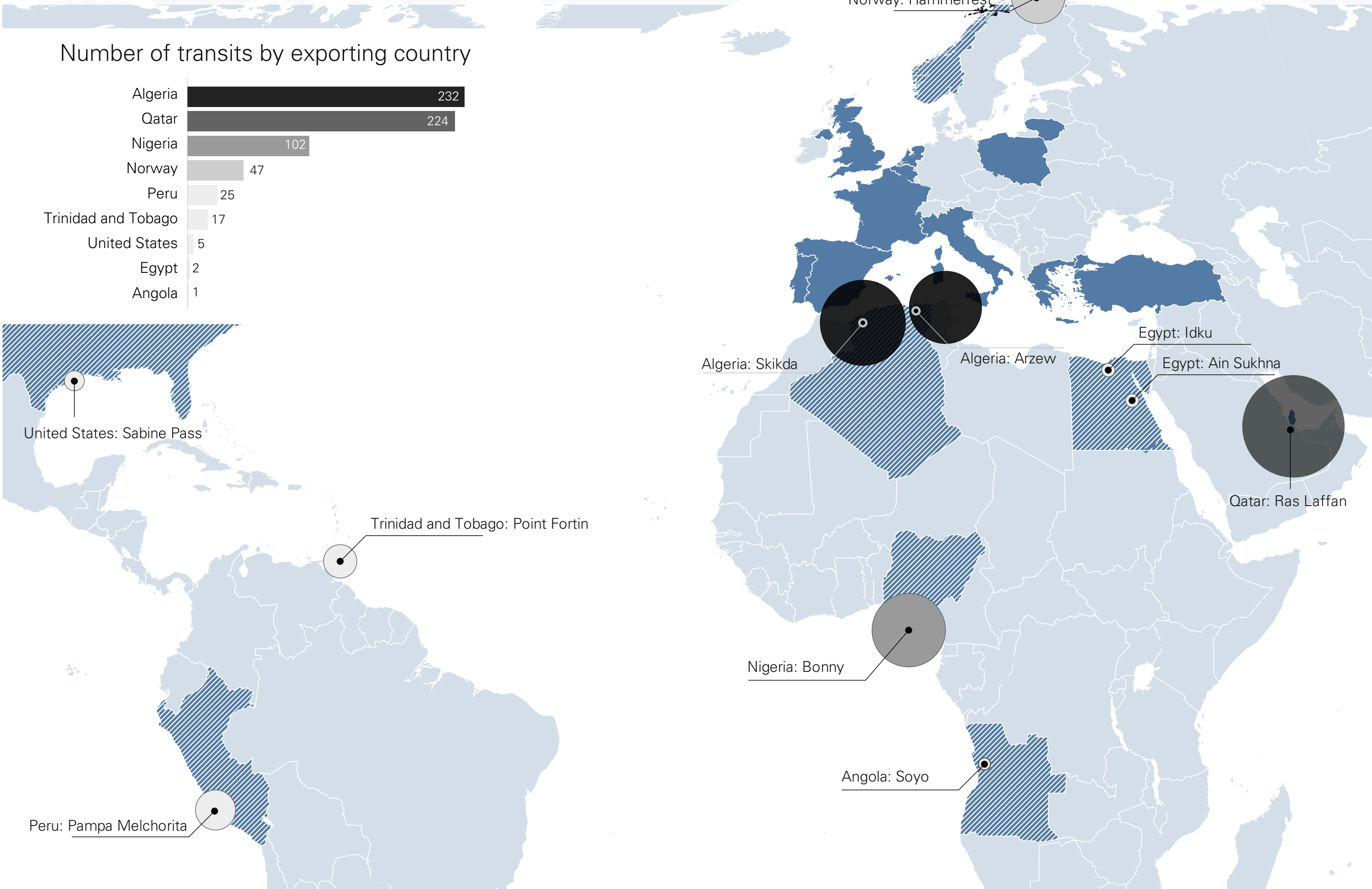
Table 6: Emissions associated with methane leakage along the gas supply chain for transits that arrived at the European ports in 2016, differentiated by countries of origin.

To improve understanding of the emissions associated with the gas supply chain, they will be expressed in terms of the annual emissions per capita of the European population[9]. Expressed thus, the results were:

- The transit that produced the least emissions (the transit from Algeria) produced emissions between 61,100 and 179,583 tCO_2eq. This is equivalent to the emissions of between 9,000 and 27,000 European citizens.
- The transit that produced the most emissions (the transit from Nigeria) produced emissions between 130,975 and 382,067 tCO_2eq. This is equivalent to the emissions of between 19,500 and 57,000 European citizens.
- The total emissions from the transits bound for European ports are between 67,623,763 and 199,914,106 tCO_2eq. This is equivalent to the emissions of between 10 and 30 million European citizens.

9 Annual emissions per capita of European citizens. World Bank: https://datos.bancomundial.org/indicador/EN.ATM.CO2E.PC?name_desc=false

LNG transits



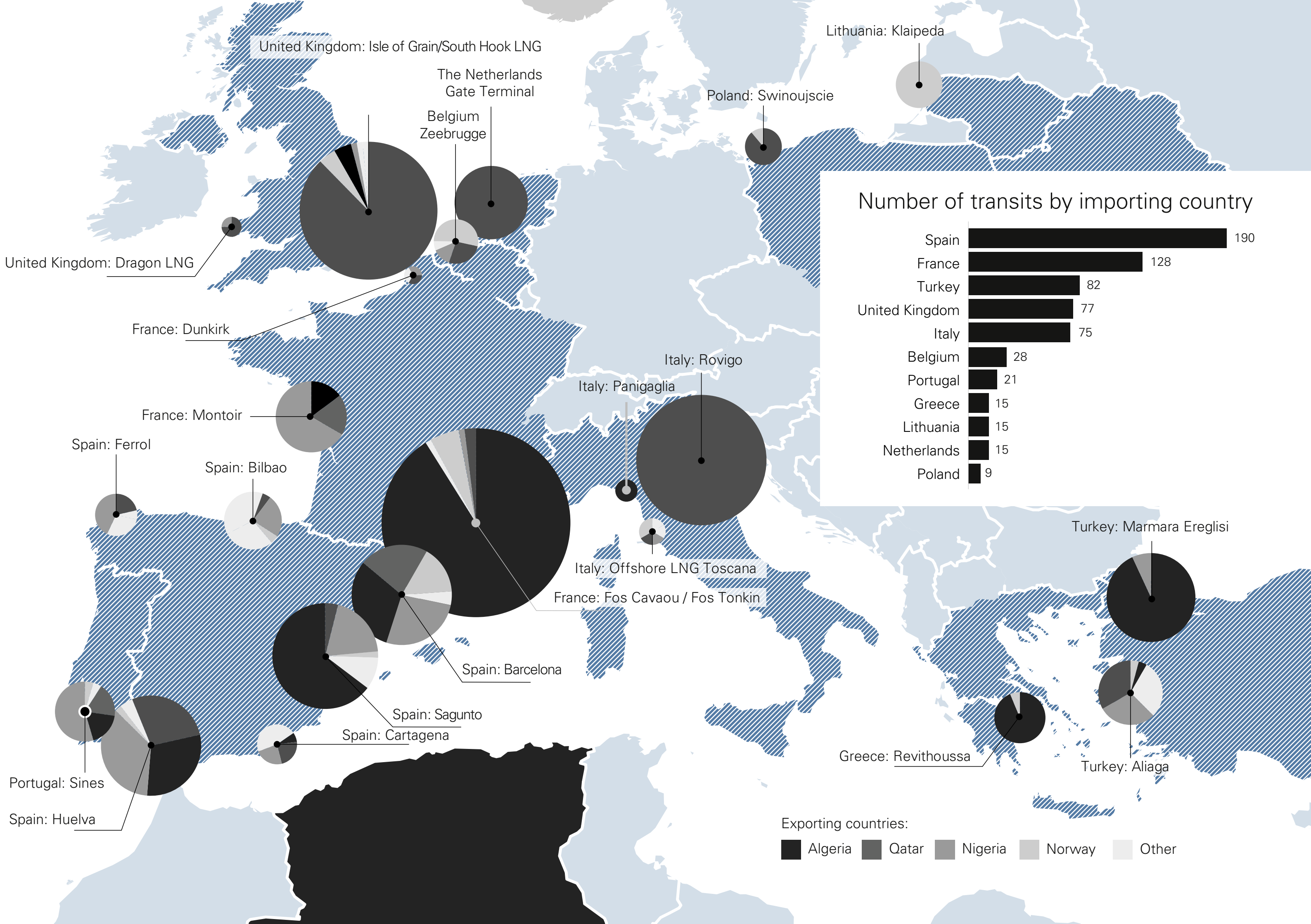

United Kingdom: Isle of Grain/South Hook LNG
The Netherlands Gate Terminal
Belgium Zeebrugge
Lithuania: Klaipeda
Poland: Swinoujscie
United Kingdom: Dragon LNG
France: Dunkirk
France: Montoir
Spain: Ferrol
Spain: Bilbao
Italy: Rovigo
Italy: Panigaglia
Italy: Offshore LNG Toscana
France: Fos Cavaou / Fos Tonkin
Spain: Barcelona
Spain: Sagunto
Spain: Cartagena
Portugal: Sines
Spain: Huelva
Turkey: Marmara Ereglisi
Greece: Revithoussa
Turkey: Aliaga
Number of transits by importing country
Spain 190
France 128
Turkey 82
United Kingdom 77
Italy 75
Belgium 28
Portugal 21
Greece 15
Lithuania 15
Netherlands 15
Poland 9
Exporting countries:
Algeria
Qatar
Nigeria
Norway
Other

Figure 3:
Classification of European countries that imported LNG in 2016, according to the amount of LNG imported and the exporting country

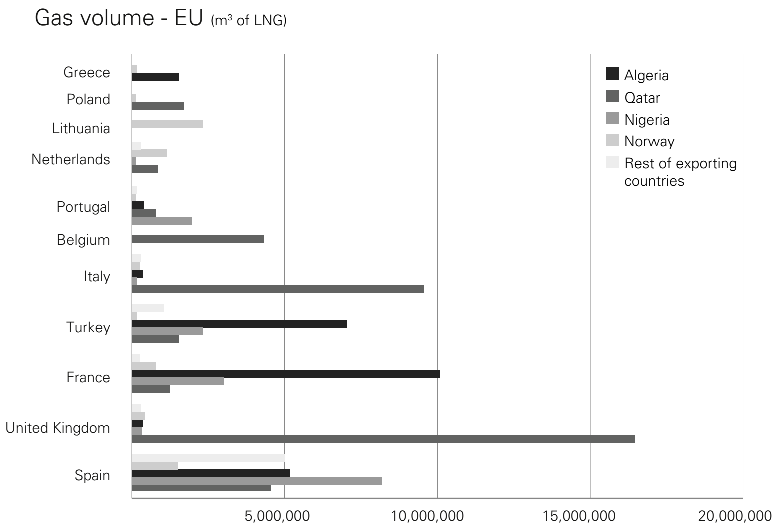
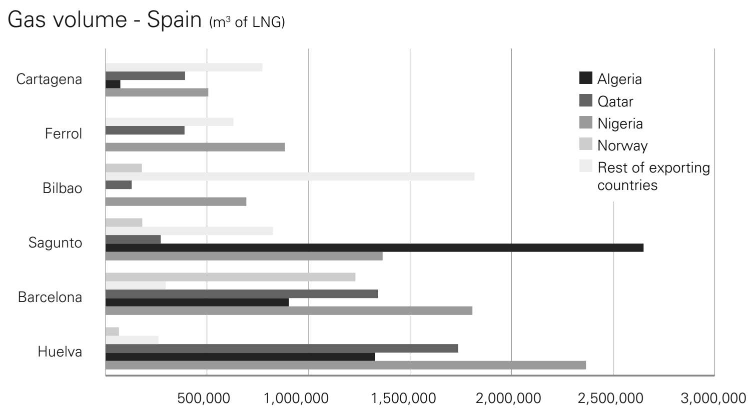


Figure 4:
Classification of Spanish ports that imported LNG in 2016, according to the amount of LNG imported and the exporting country



8. The importance of the port of Barcelona in the European gas market

8.1. Characterisation

One of the European Union's initiatives in the energy (specifically the gas) sector is to reduce dependence on Russia by enlarging infrastructure and diversifying gas exporters. This goal means that the Spanish government and especially the port of Barcelona have an important role at a geostrategic level due to their geographic location and regasification capacity: both the pipelines interconnecting the country with Algeria and the regasification plants situated in the six ports currently operating.

It must also be taken into account that Spain is the fourth country in the world by regasification capacity and represents 36% of capacity within the European Union, despite the fact that its LNG usage is significantly less (Hamouchere & Pérez 2016).

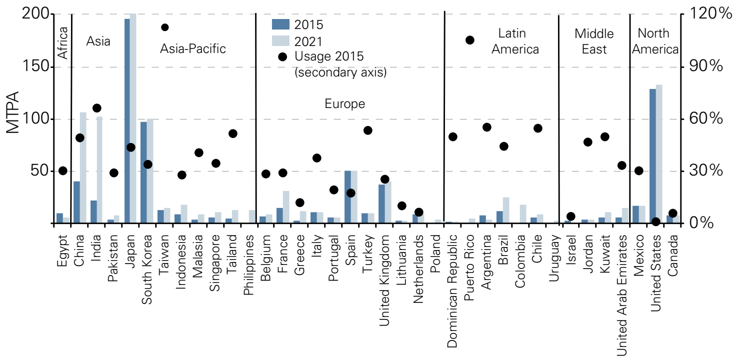


Figure 5: Importing plants capacity in million tonnes per annum (MTPA) and its usage ratio in percentage. (Source: World LNG Report 2016 IGU)[10]

The seven importation plants located in Spanish territory (six operational and one not currently used) have a combined capacity of 68.9 bcm[11]. The three biggest providers of LNG to Spain are Nigeria, Algeria and Qatar. However, Algeria is the export leader for Spain via two pipelines which connect Algeria directly with Spain.

The regasification plant in the port of Barcelona has a capacity of 17 bcm, which represents 24.67% of Spanish and 8.18% of European Union regasification capacity. Its importance is also due to the fact that it was the first regasification plant constructed in Spain and one of the first in the EU, dating back to 1968. Like most European regasification plants, the usage level of the Barcelona plant has never exceeded 50% and normally lies at around 15-20%.

10 International Gas Union (2016): www.igu.org/publications/2016-world-lng-report

11 1 bcm is equivalent to 10^9 m^3

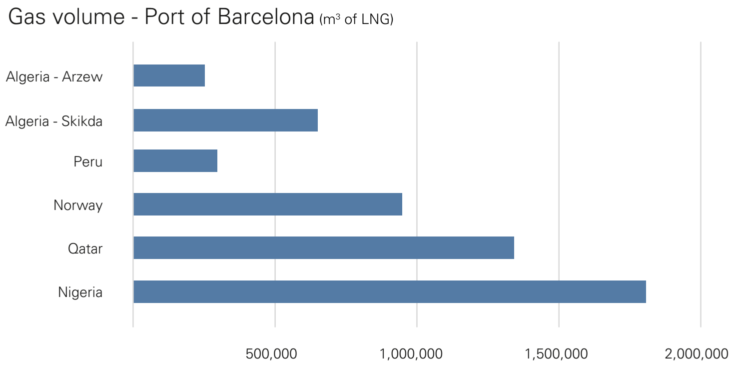


Figure 6: Emissions associated with methane leakages produced along the gas supply chain by the transits that arrived at the port of Barcelona in 2016, differentiated by country of origin.

Gas arriving at the port of Barcelona is transported to the city or to other municipalities via the pipeline network. In recent years, the port installations have been used for re-exporting gas whereby gas is imported from traditional exporters (Qatar, Algeria, Nigeria, etc.) and re-exported to Brazil, Japan, South Korea, India, etc. This is motivated by gas market prices and "take or pay" contracts: firstly, the Asian market (a net importer) has always paid very high gas prices, which makes it a lucrative market, and secondly, contracts with "take or pay" clauses require payment for quantities of gas which are not imported. The fall in domestic consumption combined with these clauses means that it is cheaper to import gas and re-export it, even though this is not a rational and efficient use of resources (Hamouchere & Perez 2016).

Another salient point is that the port of Barcelona and Bilbao are the closest ports to the French border. Therefore, they offer the opportunity to transport gas throughout the EU through pipelines. According to the European Commission (EC), the Spanish state has a lack of gas and electrical interconnection infrastructure, hence the construction of a large new gas pipeline, MidCat, to interconnect the Catalan networks with French networks. The gas pipeline has met strong opposition from local communities along its route as it represents a commitment to a fossil fuel-based energy future and does not benefit the territories it passes through.

It could be said that gas import ports like the port of Barcelona act as real "hubs" for gas distribution, interconnecting suppliers with consumers. In addition, despite not being a focus of this study, it needs to be highlighted that corrupt and authoritarian regimes are present within gas exporting countries where national and transnational elites benefit directly from hydrocarbon business (Llistar & Pérez 2016).

The socio-environmental impacts of the petroleum and gas industry are well documented, but this does not mean that they have been re-

Country	Algeria	Nigeria	Qatar
IDH 2015	! 0.736	✘ 0.514	✔ 0.85
POS. 1-188	83	152	32
HDI CATEGORY	high	low	very high
DEMOCRACY INDEX 2015	✘ 3.95	! 4.62	✘ 3.18
POS. 1-167	118	108	134
TYPE OF REGIME	Authoritarian	Partial democracy	Authoritarian
GLOBAL PEACE INDEX 2015	! 2131	✘ 2910	✔ 1568
POS. 1-162	104	151	30
FRAGILITY OF THE STATE 2016	✘ 78.3	✘ 103.5	✔ 45.1
POS. 1-178	89	169	119
STATE FRAGILITY	Risk	High alert	Stable
PERCEPTION OF CORRUPTION	✘ 36	✘ 26	✔ 71
POS. 1-167	88	136	22
GINI COEFFICIENT	0.353	0.488	-
YEAR	1995	2010	2012

Figure 7: Indexs proposed by different organizations in order to evaluate the main LNG exporting countries to the EU in 2016.

medied. However, returning to the dimension of climate impacts, can we evaluate the emissions associated with LNG transits bound for the port of Barcelona? Put another way, can we quantify the emissions associated with LNG from extraction to arrival at the port?

8.2. Results

For the 44 LNG carriers which arrived at Barcelona's regasification plant in 2016, an estimation of emissions for each operation was made using the ranges of emission factors established by Howarth et al. (2011), except operations corresponding to the LNG supply chain, which were estimated using the calculations outlined in this report. The capacity of the LNG carriers listed for each country corresponds to the carrier which made most transits to the port of Barcelona during the year 2016.

To improve understanding of the emissions associated with the gas supply chain, they will be expressed in terms of the annual emissions per capita of the European population[12].

12 Annual emissions per capita of European citizens. World Bank: https://datos.bancomundial.org/indicador/EN.ATM.CO2E.PC?name_desc=false

Expressed thus, the results were:

- The transit that produced the least emissions (the transit from Algeria) produced emissions between 59,959 and 178,443 tCO_2eq. This is equivalent to the emissions of between 9,000 and 26,500 European citizens.
- The transit that produced the most emissions (the transit from Peru) produced emissions between 127,224 and 359,926 tCO_2eq. This is equivalent to the emissions of between 19,000 and 54,000 European citizens.
- If we add all the emissions from the transits bound for the port of Barcelona, we obtain a range of emissions from 4,488,789 to 13,032,531 tCO_2eq. This is equivalent to the emissions of between 670,000 and 2 million European citizens.

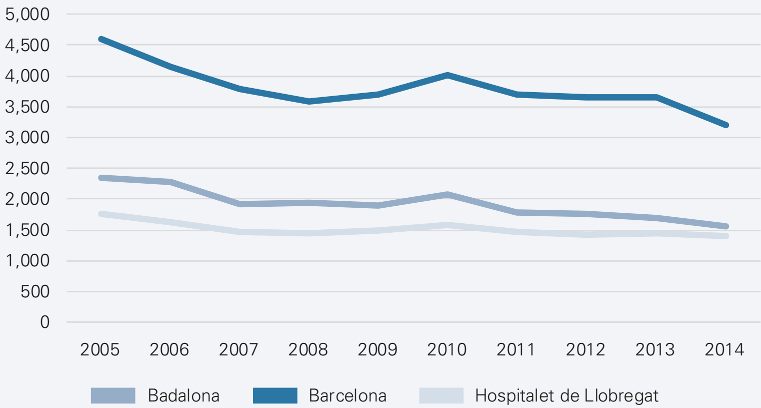
Table 8: Emissions associated with methane leakages produced along the gas supply chain by the transits that arrived at the port of Barcelona in 2016, differentiated by country of origin.

Country of origin	Capacity of LNG carrier(m^3)	Emissions (tCO_2eq)	
Nigeria	141,021	Min.	113,567
		Max.	334,874
Algeria	75,500	Min.	59,959
		Max.	178,443
Qatar	138,273	Min.	114,403
		Max.	333,470
Norway	147,980	Min.	127,777
		Max.	354,757
Peru	155,000	Min.	127,224
		Max.	359,926

Gas in Barcelona

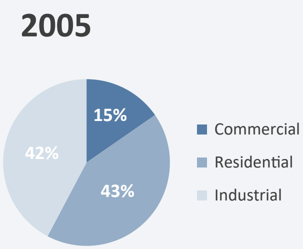
Gas consumption in the city of Barcelona has experienced the same decline as in other cities and territories, principally due to the economic crisis. The presence of big gas sector businesses in Barcelona, like Gas Natural Fenosa, firmly establishes Barcelona in the gas industry, despite being a Mediterranean city with a climate that theoretically does not call for large heat inputs to maintain thermal comfort in homes.

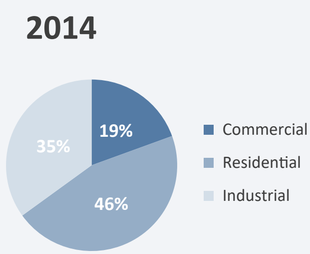
Consumption per capita kWh/year (Source: AMB)



The largest consumers are the domestic and industrial sectors. There were not notable changes in consumption in the last decade, although it is necessary to analyse the internal dynamics of each sector in depth. In Spain, for example, the drop in gas consumption was caused principally by low usage of combined cycle plants. The domestic sector, however, experienced a slight decrease in consumption, despite the suffering of many families trying to pay energy bills.

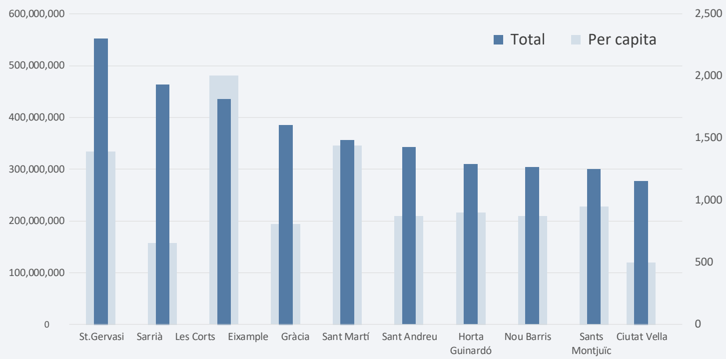
Gas consumption by sector in the city of Barcelona (Source: AMB)





The data disaggregated by district reveals that gas consumption is concentrated in the districts with the most income per capita and is especially visible when calculated per resident.

Natural gas consumption in the residential sector kWh/year (2013) (Source: AMB)



9. The rise of the US in the global LNG market

9.1. Characterisation

Although the US only sent 5 transits to the European Union in 2016, it is projected that in the coming years this figure will increase, and that the US could become a major exporter at a global level. For this reason, the emissions associated with transits from the US to the European Union, to Spain and to the port of Barcelona were evaluated. It should be remembered that, at present, it is the only country which exports unconventional gas, entailing a greater climate impact.

The chosen representative transit at European Union level was that bound for Portugal in 2016, since it was the only transit using a large conventional LNG carrier. At Spanish level, the transit that arrived in Ferrol this year in a small conventional carrier was taken as representative. For the port of Barcelona, the emissions that the transit would involve if it were sent in the same LNG carrier were estimated. It is important to note that Gas Natural Fenosa has rented 4 LNG carriers to import unconventional gas from the liquefaction plant in Sabine Pass (US) in the next twenty years (The Free Organisation 2017).

It is also important to emphasize that the estimated emissions for the port of Barcelona were made only by means of theoretical assumptions since there were no transits in 2016. This method results in rather low values compared to real transits, for example that chosen for the Spanish case.

9.2. Results

For the 5 LNG carriers that left the US to the European Union during 2016, the estimation of emissions for each operation was made using the ranges of emission factors established in the study by Howarth et al. (2011), except those that correspond to the LNG supply chain, which were estimated using the calculated methods outlined in this report.

To improve understanding of the emissions associated with the gas supply chain, they will be expressed in terms of the annual emissions per capita of the European population[13].

Table 9: Emissions associated with methane leakage along the gas supply chain for transits from the US to Portugal, Spain, and the port of Barcelona.

Transit	Capacity of LNG carrier (m^3)	Emissions (tCO_2eq)	
Portugal (real)	174,000	Min.	278,239
		Max.	551,301
Spanish State (real)	138,000	Min.	218,852
		Max.	435,418
Port of Barcelona (projection)	138,000	Min.	130,985
		Max.	374,702

Expressed thus, the results were:

- The real transit that produced the least emissions (the transit to Spain) produced emissions between 218,852 and 435,418 tCO_2eq. This is equivalent to the emissions of between 32,500 and 65,000 European citizens.

- The real transit that produced the most emissions (the transit to Portugal) produced emissions between 278,239 and 551,301 tCO_2eq. This is equivalent to the emissions of between 41,500 and 82,000 European citizens.

- If we add all the emissions from the transits bound for the European ports, we obtain a range of emissions of 1,153,645 to 2,292,974 tCO_2eq. This is equivalent to the emissions of between 170,000 and 340,000 European citizens.

13 Annual emissions per capita of European citizens. World Bank: https://datos.bancomundial.org/indicador/EN.ATM.CO2E.PC?name_desc=false

10. Conclusions

In the vast majority of international treaties and political circles, there is an assumption that the ideal timescale for evaluating the climate impact of greenhouse gases is 100 years, although the 5th report from the IPCC specifies that there is no scientific argument to support this. Considering the lifetime of methane in the atmosphere, the ideal timescale to evaluate its contribution to global warming is 20 years. The 4th and 5th IPCC reports have quantified the Global Warming Potential (GWP) of methane for this timescale as 72 and 86, respectively. When the direct radiative effects of methane are considered, the GWP is 79 as estimated by Shindell et al. (2009), and this value increases to 105 if both indirect and direct effects are considered.

Considering the GWP of methane and the methane leakage present throughout the gas supply chain, the study by Alvarez et al. (2012) establishes that the percentage of methane leaks above which the gas ceases to have a climate benefit with respect to coal is 3.2%. The values estimated by Howarth (2014) and Sanchez & Mays (2015) are 2.8% and 3.7-3.9%, respectively. The IEA's WEO 2017 gives the limit as 3%. All the studies and reports consider the leaks from the extraction of the gas until the point of electricity generation and use a 20 year timescale.

Although the different "coal thresholds" vary by little more than 1%, there is huge variability in the values used to estimate gas leaks at each one of the operations and stages that comprise the supply chain. This lack of consensus could be resolved through: 1) a deeper understanding of the sources of gas leaks in fields; 2) an agreement on the methodologies used; and 3) the intervention of independent scientists. On this last point, one must emphasize the considerable costs and complications involved in measuring leaks from gas infrastructure, since it is the industry itself that determines in which wells measurements can be made.

Considering the transits which arrived in the European Union in the year 2016, the emissions produced from the extraction of the gas until it arrives at its port of destination by the transit producing least emissions are equivalent the annual emissions of between 9,000 and 27,000 European citizens. Those corresponding to the transit with the most emissions are equivalent to between 19,500 and 57,000 citizens' emissions, and the total emissions of all the transits are equivalent to the emissions of between 10 and 30 million European citizens. For the port of Barcelona, the emissions associated with the transits that produced the most and least emissions are similar, since they come from the same port of origin and the capacity of the LNG carriers is similar. The total emissions corresponding to the 44 transits that arrived in the port of Barcelona in the year 2016 is equivalent to the emissions of between 670,000 and 2 million European citizens. In the case of the US, the emissions associated with the transit to the European Union that produced the least emissions produced emissions equivalent to those of between 32,500 and 65,000 European citizens, while the emissions of the transit producing the most were equivalent to the emissions of between 41,500 and 82,000 citizens. The sum of the emissions from the 5 transits accounts for the emissions of between 170,000 and 340,000 European citizens.

Considering the results of the study, it seems clear that if we look beyond emissions due to combustion, natural gas is not a friend to the environment. It is an incontrovertible fact that the combustion of gas generates fewer CO_2 emissions than petroleum or coal. However, if we calculate its emissions considering the entire supply chain and incorporating methane leaks, its contribution to the fight against the climate change is questionable and, in many cases, leaks even exceed the "coal threshold". Besides, attention should be paid to the eruption of unconventional gas into the global gas market. According to the emission calculations by Robert Howarth, its entry would drive up methane emissions and could cause impacts in a short time.

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