SURVEY METHANE EMISSIONS FOR LNG TERMINALS IN EUROPE

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1. SUMMARY

The impact of Greenhouse Gases on climate change has been recognized for some time which has led to measures aimed to reduce global warming. Methane (CH_4) is the major component of Natural Gas and is identified as a Greenhouse Gas.
As Natural Gas is a major source of energy for the society, it is the role of the gas network operators to deliver continuous and safe service whilst managing responsibly the impacts on the environment.

MARCOGAZ, the Technical Association of the European Gas Industry, considers that it is important for the Gas Industry to understand and quantify its emissions of Natural Gas. It is also important to be transparent about the methodology used to calculate the emissions and to demonstrate that best practices are used across the European Gas Industry.

This study is a first attempt to make an estimation of the total methane emissions for the 20 Liquefied Natural Gas terminals (LNG terminals) in the EU28. Together with the reports that MARCOGAZ is going to publish for transmission, distribution-grids and underground storage facilities, this report aims at estimating the total methane emissions along the so-called mid-stream sector of Natural Gas.

For this study, several LNG terminals operators were asked to deliver their emission data of the year 2015 according to a method which was developed by MARCOGAZ. 13 out of 20 terminals in operation in 2015 provided data to support this study. However, only 9 could be considered as a representative set from which the other LNG terminals' CH_4 emissions can be estimated.

The data received from those 13 LNG terminals represents 66% of the total maximum send-out in the EU28 in 2015 whereas the selected representative dataset (9 terminals) is representing 38% of the total maximum send-out in the EU28 in 2015.

Based on that study the average emission per year from the European LNG terminals is:

0,12 g CH_4/m^3_n (send-out)[1]

- ✓ The total calculated amount of methane emissions for 18[2] out of 20 LNG terminals in operation in EU28 in 2015, is in the range of:

  4,7 kT of CH_4

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[1] This ratio should not be used to estimate emissions for a completely different scenario with higher send-outs as there is still no strong evidence regarding the proportional relationship between emissions and send-out. It will be addressed in future studies.

[2] Although the intention was to estimate the total methane emissions from the 20 LNG terminals in operation in 2015 in the EU28, it was only possible to do it for 18 out of 20 (see following pages).

- ✓ The total amount of methane emissions caused by LNG terminals are estimated to be:

  < 0,002% of the gas sales[3] in the EU28

- ✓ On that basis, methane emissions from LNG terminals, expressed in CO_2 equivalent, are estimated to be:

  131,6 kT CO_2eq[4]

The total amount of GHG emissions caused by the methane emissions from LNG terminals is estimated to be **below 0,003 % of the total of anthropogenic GHG emissions in Europe (EU28)[5].**

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[3] Source: EU28 inland gas sales: EUROGAS Statistical report 2015

[4] GWP: Global Warming Potential; GWP_{100} of CH_4 (= 28) is used according to the Fifth Assessment Report (AR5) - IPCC.

[5] Approximated European Union greenhouse gas inventory: Proxy GHG emission estimates for 2015, EEA report No 23/2016, page 76

2. INTRODUCTION

In the past ten years, an increasing number of reports from reputable institutions have highlighted the environmental impact of global warming and the accelerating effect that the continuous release of Greenhouse Gases to the atmosphere is having on this phenomenon.
This changing attitude of governments, regulatory bodies and the public in general has resulted in increasing attention being paid to the methane releases from the gas networks across Europe.

Although some data are available, it is not easy to interpret the results from these studies and to make analyses on a technical level possible.

A literature review showed that, on a European level, no detailed study on methane emissions from LNG terminals was available.

This was the reason for MARCOGAZ and GIE[6] to invoke a study on methane emissions from LNG terminals in Europe. In 2016, a method and a questionnaire were prepared with specialists of some of the LNG terminals.

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[6] GIE: Gas Infrastructure Europe

3. LIST OF DEFINITIONS

In order to obtain comparable and objective emission calculations or estimations, the use of identical definitions is necessary. For this reason, a number of definitions are given hereunder.

3.1. Emissions: sources of methane

- *Fugitive emissions*: All residual leaks from flanges, pipe equipment's, valves, joints, seals and seal gas systems etc. that are more or less continuous sources.

- *Pneumatic emissions*: All emissions caused by gas operating valves, continuous as well as intermittent emissions.

- *Vented emissions*:
  - *Maintenance vents:* Methane emissions from planned operating conditions where significant volumes of Natural Gas can be released to atmosphere from the gas network for maintenance purposes.
  - *Incident vents:* Methane emissions from unplanned events. This will normally be from failures of the system due to third party activity and external factors normally outside of the control of the gas company.
  - *Operation vents:* i.e. starting and stopping of the compressors.

- *Incomplete combustion emissions:* Unburned methane in the exhaust gases from gas turbines, gas engines and combustion facilities and flares.

3.2. Gas system

- *LNG terminal*: Storage and gasification of LNG, including ship loading/unloading and truck loading and a variety of above-ground facilities to support the overall system.

3.3. Emissions measurement methodology

The LNG terminal operators in Europe underline the importance of measuring and reducing methane emissions. They have accumulated extensive knowledge and experience in recent decades around methane emissions quantification and mitigation. They monitor their own emissions and maintain intensive programs to reduce methane emissions.

Monitoring of the emissions are typically done by measurement in case of fugitive emissions. In some cases, the whole population of a specific kind of asset is measured; in other cases, the fugitive emissions are calculated from a population sample, depending of course of the size of the asset population. For the measurement of fugitive emissions, the EN15446 measurement method offers an approach to determine emissions from equipment leaks by providing an equation to predict mass emission rate (in kg/h) as a function of screening value (ppm-mol) for a particular equipment type. The correlation factors are empirical equations based on field data and they were developed for the Synthetic Organic Chemical Manufacturing Industry (SOCMI) and for the Petroleum Industry (PI). The Air Flow Method (Hi Flow Sampler device – HFS) offers an approach to measure emissions from equipment leaks in specific situation.

Calculation is often performed in case of vented emissions. In this situation, the total mass of methane is calculated from the length of the pipeline, the pressure, the diameter and the composition of the gas.

For pneumatic emissions, both measurement and estimation are used.

3.4. Geographical boundaries

This study is a first attempt to make an estimation of the total methane emissions from the 20 LNG terminals in operation in 2015 in the EU28. See §7.2 - APPENDIX II: LNG terminals included in this study.

4. RESULTS

4.1. Data collection

MARCOGAZ and GIE prepared a survey circulated among their Members in January 2017 asking them to fill in the form of the MARCOGAZ method (See § 7.1 - APPENDIX I: MARCOGAZ forms methane emission). The form was returned by 9 MARCOGAZ / GIE members, which means data was received for 13 LNG terminals out of 20 in operation in 2015 in EU28.

Operators were asked to fill in the form with the emissions of the different parts of their installations and to give activity data where available.

The corresponding 13 LNG terminals represent about 66% of the total maximum send-out in the EU28 in 2015.

4.2. Description of the method

The evaluation of total emissions is based on the following equation:

$$\boldsymbol{Methane\ emission} = \sum(\boldsymbol{AF} \times \boldsymbol{EF})$$

Where:

AF = activity factor
EF = emission factor

The **activity factors** are the population of emitting equipment's such as maximum send-out of the terminal (in m_n^3/h), length of pipelines, number and type of valves, number and type of pneumatic devices, or the frequency of emitting events such as number of operating vents.

The **emission factors** are defined as the quantity of methane emitted from each emitting source or for each emitting event. Some emissions are known, such as the gas released for operating reasons or for maintenance, some others can be evaluated on the basis of the characteristics of components and their emission factors, the emission from the operation of a pneumatic device. Other emission factors are difficult to measure such as those deriving from fugitive emissions. For fugitive emissions, several measurements methods exist.

4.3. Evaluation of the quality of the data set

9 companies (A to I) provided data for 13 LNG terminals. Nevertheless, the required data were not always sent according to MARCOGAZ format and some important information (such as origin of the data, or data for all emission sources) was not provided.

For all the above reasons, all data from the 13 LNG terminals cannot be used to do the extrapolation so that a representative dataset should be selected.

The next table gives an overview of the data delivered by the 9 companies for the 13 LNG terminals.

Legend:

red: data not provided (empty cell)

green: data provided (0 or any other)

	Company								
Source	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Fugitive emissions									
LNG	green	green	green	red	red	green	green	red	red
Boil-off gas	green	green	green	red	red	green	green	red	red
High pressure gas	green	green	green	red	red	green	green	red	red
Liquefaction	green	green	green	red	red	green	green	red	red
Pneumatic emissions									
Pneumatic valves	green	green	green	red	green	red	green	red	red
Analysers	red	green	green	red	green	red	green	green	red
Compressor seals	green	green	green	red	green	red	red	red	red
Vents									
Maintenance	green	green	green	red	green	green	green	red	red
Operation	green	green	green	red	green	green	green	green	green
Incidents	green	red	green	red	green	green	green	green	red
Combustion									
Flares	green	red	green	green	green	green	green	red	red
Boilers	green	red	green	red	green	green	green	red	red
Submerged combustion vaporizers	green	green	green	red	green	green	green	red	red
Generators	green	red	green	red	green	green	green	red	red

Table 1: 2015 dataset for LNG terminals

For these 13 LNG terminals, 60% of the emission data fields (see §7.1) were declared.

We have to note that 70% of the (13) LNG terminals that provided data for this study, have declared fugitive leaks, which is particularly important when established that fugitive leaks are representing between 66% and 100% of the declared CH_4 emissions.

4.3.1. Further analysis, definition of representative dataset

This dataset is representative. The same criteria as for the transmission report (MARCOGAZ ref. WG-ME-17-09) was used, so that the data collected will be considered representative only if it fulfils both of the following criteria:

1) a minimal completeness of the data provided (at least 7 fields filled on 14 possible)
2) and a minimal amount of declared fugitive leaks of 10% of the total declared CH_4 emissions (since the importance of fugitive leaks in the 2015 dataset was between 66% and a maximum of 100% of the total methane emissions)

Applying these criteria, for the 16 LNG terminals in the EU28 with flare or with an emergency vent not used in 2015, the representative dataset is made of 8 LNG terminals belonging to the companies: A, C, F, G. Data from those 8 LNG terminals were used in this study as a representative dataset to estimate the emissions for the other 8 LNG terminals that have a flare but whose data has not been provided.

Regarding the 4 remaining LNG terminals:

- We know that 2 out of these 4 have a vent instead of a flare and this vent was used in 2015 to released natural gas directly to the atmosphere. 1 of these 2 terminals without flare provided data for almost all sources, so it is considered as representative and is not necessary to make any estimation. However, the other terminal with no flare, provided only the data for vented gas (not representative). Therefore, other emissions (mainly fugitive) were calculated by an extrapolation from other terminals since there is a relation between fugitive emissions and send-out.
- There is no information about the 2 remaining terminals. Their emissions cannot be estimated based on the other terminals because we do not know if there is a flare inside or a vent.

In the end, this study provides information on the total methane emissions for 18 out of 20 EU28 LNG terminals in operation in 2015.

If considering the maximum send-out, this representative dataset (9 terminals, 8 with flare and 1 with a vent inside) is representing 38% of the European (EU28) maximum send-out in 2015.

4.4. Emission factors and European global emissions

4.4.1. Companies with flare or emergency vent not used

A correlation check for each terminal of the representative dataset has been made between the declared amount of CH_4 emitted and:

- the maximum send-out
- the 2015 send-out

Correlation factors of CH_4 emitted (kg/year) VS maximum send-out and 2015 send-out	
Maximum send-out (Nm^3/h)	2015 send-out (Nm^3/h)
85%	85%

Table 2: Correlation of representative companies' total methane emissions with diverse factors (maximum send-out and 2015 send-out)

The results are considered as acceptable for this first step in estimating CH_4 for the whole EU28 LNG terminals in operation in 2015 (except 2 terminals).

Taken into account that:

- Most of the fugitive emissions (the main contributor category) come from the compressors and the high-pressure area of the terminal, which is pressurized or not, depending on the send-out.
- Fugitive emissions are directly related to the pressure.

A single emission factor related to the yearly send-out was used instead of the maximum send-out (per design).

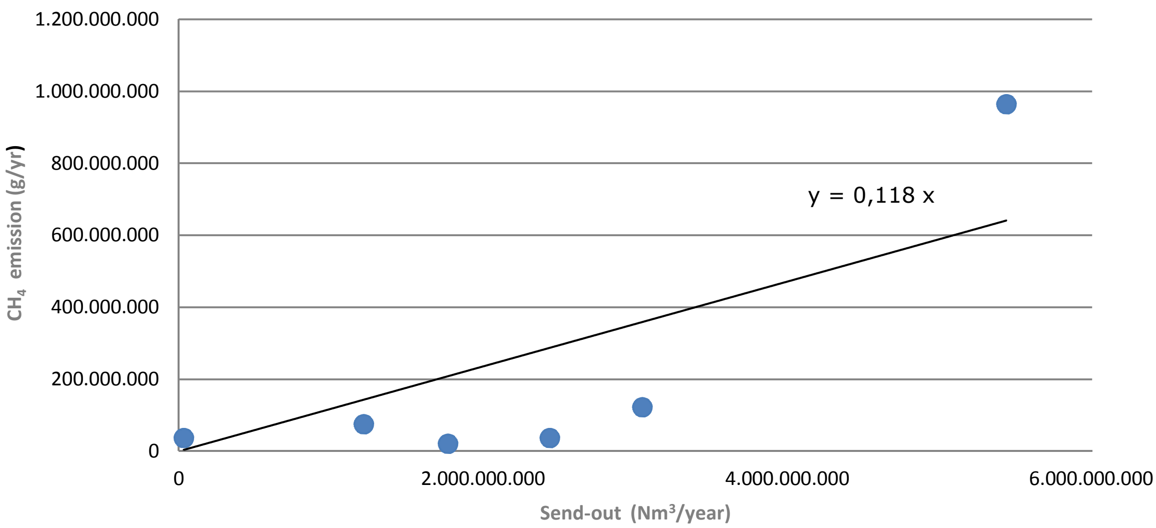

Figure 1: Total CH_4 emissions (in g CH_4) per LNG terminal of the 2015 representative dataset relative to each 2015 send-out

Note: each point represents one LNG terminal, except point with the highest emission which represents 3 LNG terminals.

Parameter	Total send-out of the 16 EU28 LNG terminals with flare or emergency vent not used in 2015 [m^3_n]	Methane emissions from the 16 EU28 LNG terminals with flare or emergency vent not used in 2015 [tons of CH_4]	Methane emissions from the 16 EU28 LNG terminals with flare or emergency vent not used in 2015 [tons CO_2eq]
Average Y=0,118 X	28.326.331.818	3.343	93.590

Table 3: Methane emissions from the 16 EU28 LNG terminals with flare or emergency vent not used in 2015

4.4.2. Terminals with no flare

In addition to the results provided in the previous paragraph (§ 4.4.1) regarding the 16 LNG terminals with flare in EU28 in 2015, we also know that 2 out of 20 terminals have a vent instead of a flare. 1 of these 2 terminals without flare, provided data for almost all sources of emission so it is considered as representative and it is not necessary to make any estimation. However, the other terminal with no flare, provided only data for vented gas (not representative) therefore, other emissions (mainly fugitives) were calculated by an extrapolation from other terminals since there is a relationship between fugitive emissions and send-out.

4.4.3. Others

According to § 4.4.1. and § 4.4.2, 16 out of the 20 terminals in operation have a flare or an emergency vent, whereas 2 have an operational vent inside instead of a flare. There is no information about the 2 remaining terminals, so their emissions cannot be estimated based on the other terminals because we do not know if there is a flare inside or a vent.

4.4.4. Total methane emissions from 18 LNG terminals

CH_4 emissions LNG terminals with flare + CH_4 emissions LNG terminals with vent:

Parameter	Methane emission from 18 out of 20 LNG terminals in operation in 2015 [tons of CH_4]	Methane emission from 18 out of 20 LNG terminals in operation in 2015 [tons of CO_2eq]
Average Y=0,118 X	4.700	131.600

Table 4: Methane emissions from 18 LNG terminals in operation in 2015

4.5. Further analysis

Based on the 2015 representative dataset, the distribution of methane emissions per source in LNG terminals with flare has been estimated as follow.

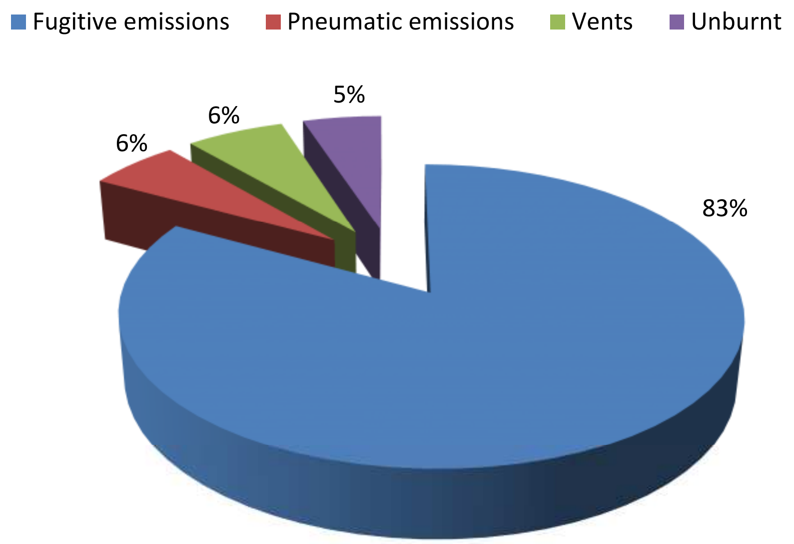

Figure 2: Methane emission sources from LNG terminals with flare

The total calculated amount of methane emissions for 18 out of 20 LNG terminals in operation in EU28 in 2015, is in the range of **4,7 kT of CH_4**

The total amount of GHG emissions caused by LNG terminals will be approximately **131,6 kT CO_2eq**

The total amount of GHG emissions caused by the methane emissions from LNG terminals is estimated to be **below 0,003 % of the total of anthropogenic GHG emission in Europe (EU28)**.

5. CONCLUSIONS

This study is a first attempt to make an estimation of the total methane emissions for the 20 LNG terminals in the EU28. Together with the reports that MARCOGAZ is going to publish for transmission, distribution-grids and underground gas storage facilities, this report aims at estimating the total methane emissions along the so called mid-stream sector of natural gas.

- ✓ Based on this study, the average emission per year from the European LNG terminals is **0,12 g CH_4/m^3_n (send-out)**[7].
- ✓ The total calculated amount of methane emissions for 18[8] out of 20 LNG terminals in operation in EU28 in 2015, is in the range of **4,7 kT of CH_4**
- ✓ The total amount of GHG emissions caused by LNG terminals is estimated to be **<0,002%** of the gas sales[9] in the EU28.
- ✓ The Methane emissions from LNG terminals are estimated at **131,6 kT CO_2eq**[10].
- ✓ Fugitive emissions are one of the main CH_4 emissions.
- ✓ In LNG terminals without a flare, the natural gas vented represents the most important contributor in terms of methane emissions.

These first findings show how the natural gas industry continues making big efforts to control and reduce its methane emissions. In fact:

- ✓ Up to 60% of the emission data fields were declared. This means that the Natural Gas Industry is making effort to control all methane emissions sources.
- ✓ Most of the EU28 LNG terminals in operation in 2017 have a flare inside.
- ✓ 70% of the LNG terminals that provided data for this study have declared fugitive leaks. LNG companies are taking action in controlling and mitigating one of the most important categories in terms of methane emissions.

Other best practices are being implementing in order to reduce methane emissions.

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[7] This ratio should not be used to estimate emissions for a completely different scenario with higher send-outs as there is still no strong evidence regarding the proportionally relationship between emission and send-out. It will be addressed in future studies.

[8] Although the intention was to estimate the total methane emissions from the 20 LNG terminals in operation in 2015 in the EU28, it was only possible to do it for 18 out of 20 LNG terminals.

[9] Source: EU28 inland gas sales: EUROGAS Statistical report 2015

[10] GWP: Global Warming Potential; GWP_{100} of CH_4 (= 28) is used according to the Fifth Assessment Report (AR5) - IPCC.

6. BIBLIOGRAPHY

- D.L. Massart, B. V. (1988). Chemometrix a textbook, Data handling in Science and Technology. Elsevier Science Publishers B.V.

- European Environment Agency. (2016). Approximated European Union greenhouse gas inventory (EEA Report No 23/2016). EEA.

7. APPENDIX

7.1. APPENDIX I: MARCOGAZ forms methane emission

METHANE EMISSION Calculation for LNG

Organisation	
Company:	Name
Emissions for the Year:	**2015**
Responsible Person:	Name

Natural Gas Composition		
Average Methane Content of Natural Gas:	90%	% (Vol.)
Density of Methane:	0.7175	kg/m³
Conversion Factor from m³ Nat.gas to g CH4:	645.75	g CH4 / m³ Gas

Calculation

No.	System Category		Activity Factors: Data	Activity Factors: Unit	Activity Factors: Measurement (M), Literature (L), Estimation (E)	Marcogaz Range*: Minimum	Marcogaz Range*: Maximum	Emission Factors: Company Data	Emission Factors: Company Unit	Emission Factors: Company Measurement (M), Literature (L), Estimation (E)	Total Emissions: Nat.Gas g/year	Total Emissions: Methane g/year	Source for own factor: Measurement (%)	Literature (%)	Estimation (%)					Remark (to describe the methodology used as well as any other remark). If case fugitive emissions have been measured by using a FID, indicate which correlation factors have been used (SOCMI, PETROLEUM INDUSTRY, OWN FACTORS...)
1.	**Terminal**																			
	Name of the LNG plant																			
	Start up (year)																			
	Inputs (Nm3/year). Amount of LNG downloaded.																			
	Truck loading (Nm3/year)																			
	Ouputs (Nm3/year). Total send out to the network (truck loading excluded)																			
	Actual Working capacity (Nm3/h), The maximun design send out. Note: If there is some equipment out of service or not in criogenic conditions such us some vaporizer or pump, do not include it here.																			
	Boil off compressed (Nm3/year)																			
1.1.	**Fugitive Emissions**												% of infrastructures measured	% of infrastructures for which literature has been used to provide data for fugitive emissions	% of infrastructures for which data has been estimated by doing an extrapolation based on the infrastructures measured	In case a LDAR campaign has been carried out, specify the the amount of Natural Gas detected in g/year (before repairing fugitive emissions)	In case a LDAR campaign has been carried out, specify the the amount of Natural Gas detected in g/year (after repairing fugitive emissions)	In case a LDAR campaign has been carried out, it is supposed that not many equipments have been working at this moment, so that the pressure is not the same and as a consequence neither the emission rates. Specify if you have taken into account the number of working hours of each equipment when extrapolating the amount of fugitive emissions detected this day to other days with higher send out.	Related to the previos column, do you have experience measuring fugitive emissions with different send-out scenarios? How does fugitive emissions rate change?	
	LNG											0								
	BOG (Boil off gas)											0								
	High pressure gas											0								
	Liquefaction											0								
	Total amount of fugitive emissions											0								
1.2.	**Pneumatic Emissions**																			
	Number of valves with pneumatic operation			No.					m3/No/a		0.0E+00	0.0E+00								
	Analyzers			No.					m3/No/a		0.0E+00	0.0E+00								
	Compressor seals			No.					m3/No/a		0.0E+00	0.0E+00								
1.3.	**Vents**																			
	Operation											0.0E+00								
	Maintenance											0.0E+00								
	Incident											0.0E+00								
	Total emission caused by vents											0.0E+00								
1.4.	**Unburnt**																			
	Flares											0.0E+00								
	Boilers for LNG process + heating boilers (buildings)											0.0E+00								
	Suberged combustion vaporizers											0.0E+00								
	Generators (gas)											0.0E+00								
1.5	**Other (please specify)**																			
											0.0E+00	0.0E+00								
											0.0E+00	0.0E+00								
											0.0E+00	0.0E+00								
2.	**Total Emissions**									Nat. Gas	0.0E+00	0.0E+00	Methane							
										t/a	0	0	t/a							

7.2. APPENDIX II: LNG terminals included in this study

Country	Name of installation	Status	Start -up year	Type	Operator short name
Belgium	Zeebrugge LNG Terminal	operational	1987	large onshore	Fluxys LNG
France	Fos-Tonkin LNG Terminal	operational	1972	large onshore	Elengy
France	Montoir-de-Bretagne LNG Terminal	operational	1980	large onshore	Elengy
France	Fos Cavaou LNG Terminal	operational	2010	large onshore	Fosmax LNG
Greece	Revithoussa LNG Terminal	operational	2000	large onshore	DESFA
Italy	Panigaglia LNG terminal	operational	1971	large onshore	GNL Italia
Italy	Porto Levante LNG terminal	operational	2009	large offshore	Adriatic LNG
Italy	FSRU OLT Offshore LNG Toscana	operational	2013	FSRU	OLT Offshore LNG Toscana
Netherlands	Gate terminal, Rotterdam	operational	2011	large onshore	Gate terminal
Portugal	Sines LNG Terminal	operational	2004	large onshore	REN Atlantico
Spain	Barcelona LNG Terminal	operational	1968	large onshore	Enagás
Spain	Huelva LNG Terminal	operational	1988	large onshore	Enagás
Spain	Cartagena LNG Terminal	operational	1989	large onshore	Enagás
Spain	Bilbao LNG terminal	operational	2003	large onshore	BBG
Spain	Sagunto LNG terminal	operational	2006	large onshore	saggas
Spain	Mugardos LNG Terminal	operational	2007	large onshore	Reganosa
United Kingdom	Isle of Grain LNG terminal	operational	2005	large onshore	Grain LNG
Lithuania	FSRU Independence	operational	2014	FSRU	Klaipedos Nafta

http://www.gie.eu/download/maps/2016/GIE_LNG_2016_A0_1189x841_FULL.pdf