POLYTECHNIC OF TURIN

Master of Science in Engineering and Management

Master Degree Thesis

Feasibility Study for the Reduction of LNG Transport Costs

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Summary

Introduction

The purpose of this document is to evaluate the possibility of building a biomethane liquefier, with the aim of being able to reduce the costs associated with the distribution and transport of LNG. The length of the supply chain highly contributes in the raising of such costs as well as the absence of an Italian-level infrastructures for the storage and production of LNG. This last point forces distributer to import LNG from France.

Bio-LNG together with LNG, are fuels suitable for heavy transport, unlike compressed natural gas whose application is more generic. The use of bio-LNG instead of LNG is irrelevant, in fact the combustion engines that burn these fuels have the same performances beyond the type of fuel used. For the time being, LNG is used exclusively as a fuel for long-range transport vehicles, ships, trains and industrial uses. The reason lies in the fact that this fuel must be stored at -162 ° C inside a cryogenic tank, which would be impossible for a commercial vehicle for obvious reasons of energy consumption. The LNG therefore offers exactly the same performance as a diesel engine for a heavy transport vehicle.

The objective of the thesis is pursued through the analysis of the entire supply chain of liquefied natural gas (LNG) and the comparison with the possible substitute product, ie bio-LNG. In this regard, therefore, the bio-LNG supply chain is also analyzed, starting from the collection of waste and specifically the organic fraction of urban solid waste (FORSU), promoting the advantages that the establishment of this market for now absent, would lead to Italy. In fact, Italy is the second biogas producing country after Germany and the third in the world after China. After that, chapter 3 deals with the reduction of the logistic supply chain based on the introduction of bio-LNG, which would allow managing the growing demand in a much more agile way.

Chapter 2 describes at a design level the biomethane and compost production plant by CTIP BLU srl, also with the aim of collecting data regarding the biomethane output that can be employed to size the liquefier for the production of bio-LNG.

The introduction of bio-LNG and LNG in the fuel network is discussed in chapter 4, highlighting the economic advantages in terms of incentives provided by the state. Chapter 5 provides the economic analysis of the construction of the liquefier near to the biomethane plant under authorization described in chapter 2.

In addition to the economic point of view, the environmental aspect is also dealt with. In particular, the last chapter aims to assess the impact, in terms of equivalent CO2, that the bio-LNG would have if it were used instead of diesel: this analysis is carried out through a "Well to Wheel" analysis applied to both LNG and bio-LNG.

Chapter 1

Waste Collection

The waste plays a role of increasing importance in Italy and in the world today. The European directives and environmental standards aim in the coming years at achieving rather ambitious quality objectives, in the context of the planetary and increasingly transversal fight against pollution. The national picture, which is still somewhat underpowered, can certainly be seen as a business opportunity for entrepreneurship, which, despite the risks associated with regulatory and administrative uncertainties, is increasingly oriented towards investing. Investment intentions that have to deal with excessive bureaucratic weight and with the widespread attitude of closure of citizenship that acts and often reacts according to the "nimby" principle.

Waste collection is the first phase that makes up a complex process whose ultimate goal is the production of secondary raw materials in order to respect the environment and reduce costs. This makes the sector attractive and innovative, which assumes a utility from the social point of view, creating value for the citizen (healthier air), the consumer (reduction of the cost of living) and the companies (new business opportunities).

This first chapter goes to investigate how the FORSU (Organic Fraction of Urban Solid Waste) is produced, initially analyzing some data to reveal the potential behind the figures for biogas production. Subsequently the methods by which the biogas is produced are analyzed, such as anaerobic digestion.

1.1 Circular Economy

The decisions taken at European level require member states to no longer consider waste as a waste object, which the company must get rid of at any cost. A new trend that involves avoiding the accumulation of waste in landfills when they still have a value: their destiny could be reuse and recovery. New concepts that lead to the affirmation of the circular economy applied to waste collection, with the differentiation of the same, under the prevention of related consortia (Corepla for plastic, Conai for packaging, etc). A true revolution that will necessarily have to be shared by different actors to achieve the desired effects:

- Public administrations, through the adoption of authorizations, programming activities, market and business regulation commitments, creation of new opportunities such as the assignment of green tenders.
- Companies, which make the requests of the PA realizable.

● Scientific and technological research institutes, providing know-how and technological innovation to address and solve problems.
● Civil society and consumers, as urban operators aware of the environmental and social challenge.

The aforementioned actors coordinate their knowledge with the aim of achieving a series of objectives [1.1]:

● Efficient and sustainable use of resources
● Change the mentality in terms of production, distribution and consumption.

Here it is proposed to evaluate a segment of the circular economy, having as ultimate purpose the analysis of the impact that biogas that, transformed into gaseous (CNG) and liquid (LNG) biomethane, has on the automotive sector and the heavy road transport. In this regard, with a view to the circular economy, the objectives specialize:

● Replacement of "fossil" fuels
● Expansion of agricultural land and increase in biomass production
● Reduction of harmful emissions

The achievement of these latter targets does not exclusively stimulate the affirmation of the bio-GNC and bio-GNL market, but has the aim of reducing the quantity of waste produced and recycling or reusing the remaining ones: it is a solution to face the "waste crisis" in which Italy pays.

1.2 Disposal and Recovery

The guidelines for the interpretation of Directive 2008/98 / EC define the preventive measures and attitudes that society and companies must take towards waste, radically changing the paradigms and meaning of their decisions. Beginning with public administrations, so far accustomed to eliminating waste by depositing it in landfills or providing for their incineration. The new political orientation has instead expressed the will to recover them, giving them a role that is finally useful to the community: in the waste recovery process the matter enters with a lower degree of entropy and comes out with an even lower one.

Waste recovery can take place in three different ways [1.2]:

● Re-use, at the top of the hierarchy of how waste can be treated; this procedure does not alter the physical state of the object which can therefore be used again for the same purpose for which it was conceived.
● Recycling, involves the recovery of material / energy through physical changes of the waste and involves the use of natural resources and energy. For example, the

organic cycle is a specific sector of recycling, which sees the treatment of waste composed mostly of food waste.

● Other types of recovery, which include all those operations that meet the definition of recovery, but do not comply with recycling or reuse.

As can be seen, reuse is preferred to recover because energy is not used to transform the material, thus lengthening the time of use of an object before it becomes waste.

1.3 Waste Production

In Italy, around 30 million tonnes of municipal waste and around 135 of special waste are produced [1.3], which places the country in a good position compared to the production of European waste. In fact, in Europe each inhabitant produces on average 4,962 kg of waste compared to 2,705 kg of Italians [1.3].

On a national geographic level instead, while the production of urban waste[1] per capita is constant, the production of special waste[2] is much more consistent in the north than in the center and south. This can be explained by the greater industrial activity in the north compared to the rest of Italy:

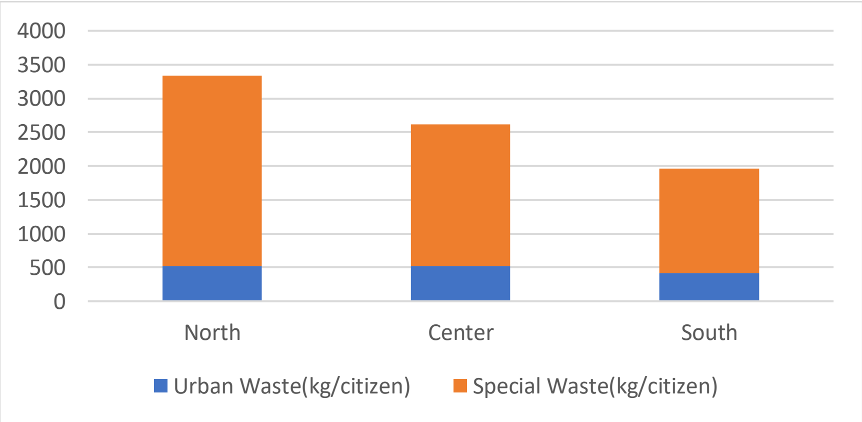

Figure 1.1 Waste production in Italy

1.4 Urban Waste

The producers of urban waste are the citizens themselves. Their destination and use is today a reason for comparison: the emergency context is asserted at national level also because it directly involves those who produce them. The collection and management of urban waste falls directly on the prerogatives of the Municipality, which takes care of its process:

[1] Urban waste is classified as: even bulky household waste, coming from rooms and places used for residential purposes, non-hazardous waste from premises and places used for uses other than those of the first point, assimilated to urban waste in terms of quality and quantity, waste coming from street cleaning etc.

[2] Special waste is classified as: Waste from agricultural and agro-industrial activities, from demolition activities, construction, from industrial processes, from artisan work, Waste from commercial activities, from service activities etc.

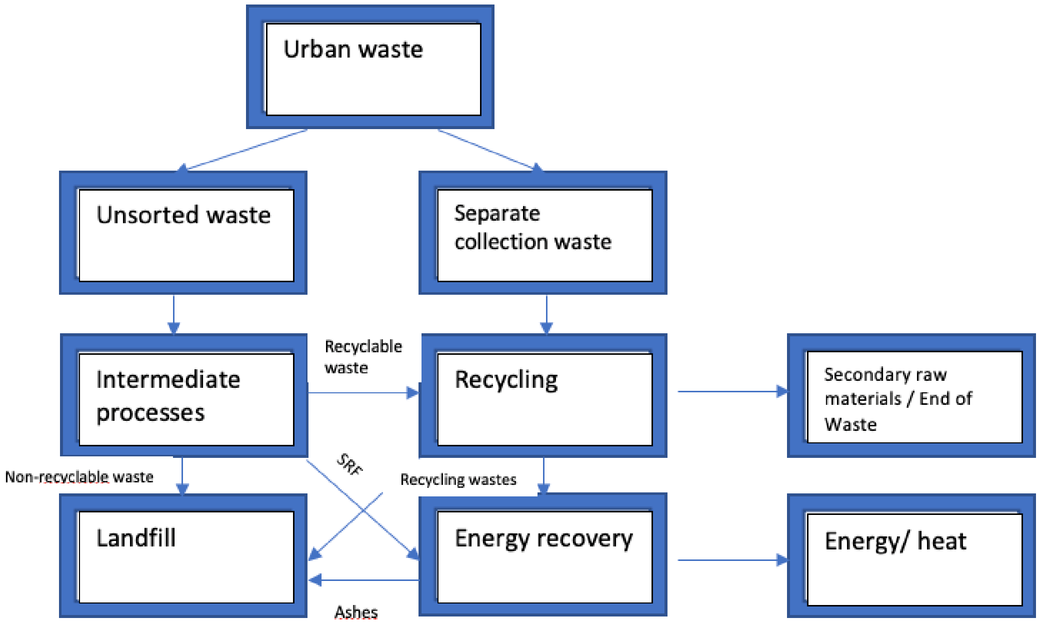

Figure 1.2 Urban waste flow scheme

From ISPRA data [1.3] it is possible to observe that 47% of urban waste is sent for material recovery: of these, 20% is recovered from the organic fraction of separate collection, while the remaining 27% is sent for recycling. Of the 20% organically recovered, 40% undergoes an aerobic / anaerobic treatment, 5% anaerobic and the remaining 55% in composting.

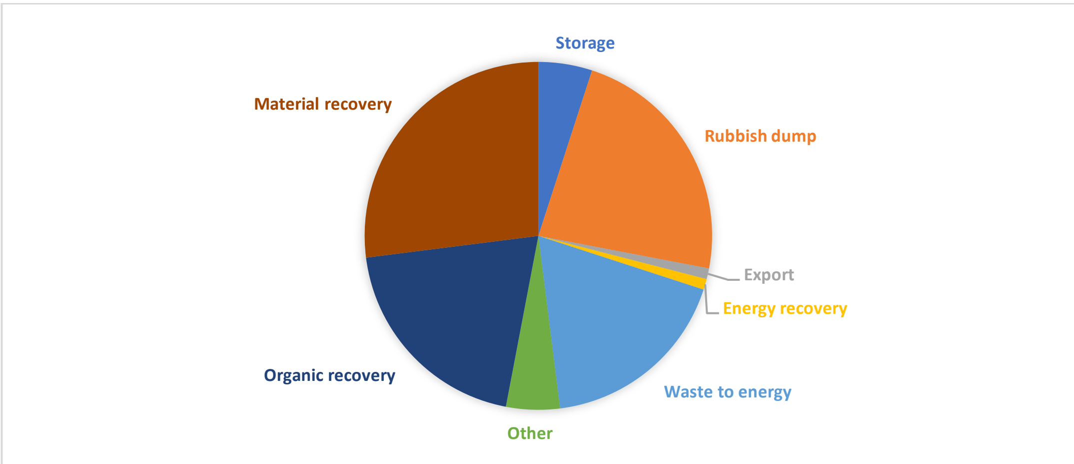

Figure 1.3 Destination and final uses of urban waste

The result of the community policies active on the territory is a net reduction of waste taken to landfill, which amounted to 46% in 2010 and to reach 23% in 2017 [1.3]. Considering the individual geographical regions, however, it is noted that the percentage of waste sent to landfill in the south is 40%, while in the north it is 12%. The European Union aims to use landfills for only 10% by 2035 and to reach this goal, member states are encouraged to use circularity [1.4].

1.5 Separate Collection of Waste

High quality separate waste collection is necessary for several reasons:

- To reduce the amount of waste to be landfilled and that of raw materials
- To safeguard the environment and improve the health and quality of life of all living species
- It brings considerable economic benefits to the company

The European directive 851/2018 does not set out precisely the objectives that each member country must achieve, in percentage terms, for each type of waste. The levels achieved in Italy in 2017 are shown below:

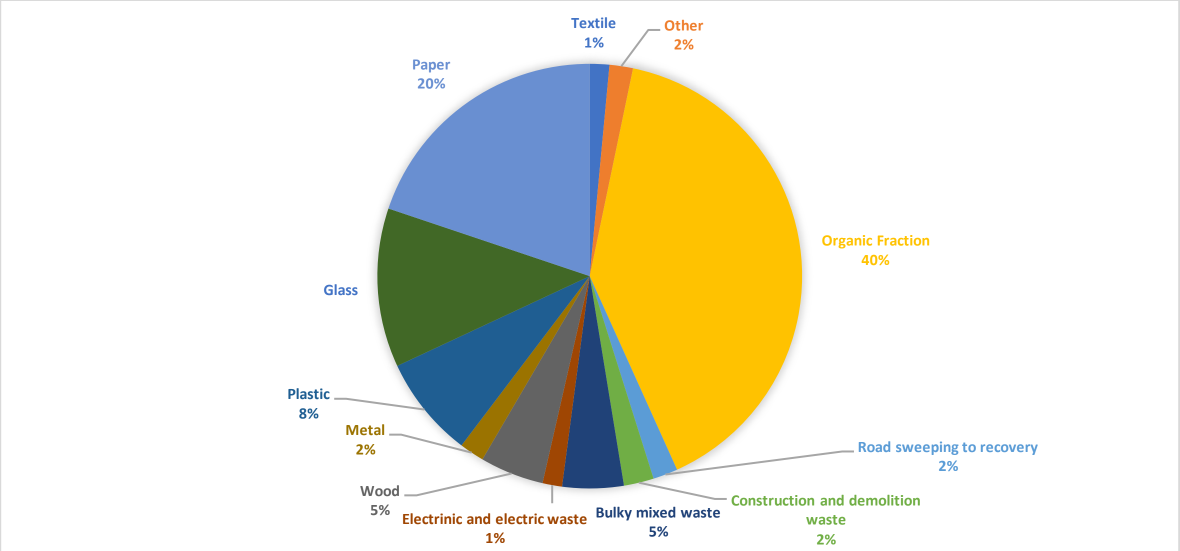

Figure 1.4 Separate waste collection in Italy

The organic fraction in the separate collection (OFMSW), represents the most abundant part of urban waste. This type of waste is subjected to recovery in different ways, for example through anaerobic digestion for the production of biogas and then biomethane.
According to the D. lgs. 152/06, Italy should have differentiated waste for 65% by 2012. Objective actually reached by the northern regions, but not by those of the center and the south. Despite this, the center and the south show a growth of 4% and 3% respectively, compared to the previous year. A 20% surcharge was applied to all the municipalities that did not reach this milestone to the landfill waste transfer fee.
As can be seen from the figures below, the 65% target has not yet been reached, despite the fact that 2012 has been imposed as the last threshold.

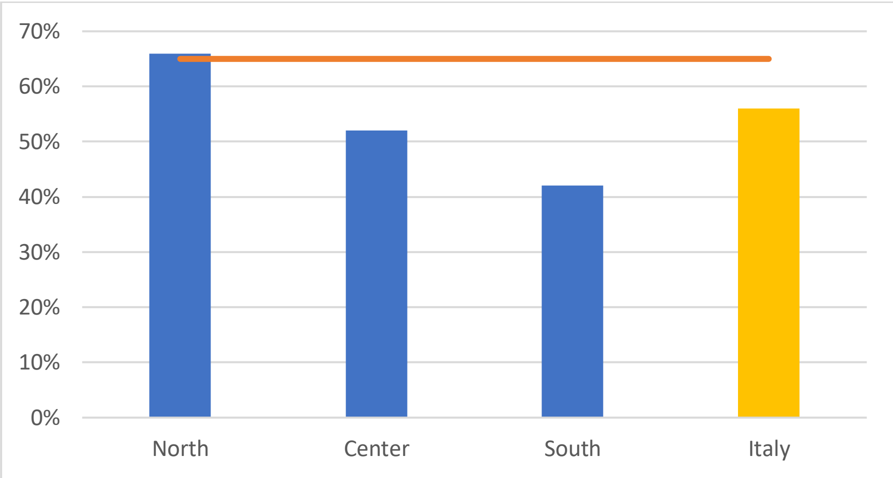

Figure 1.5 Percentage of separate urban waste collection

1.6 Unsorted Waste

The mixed fraction undergoes a cold process called mechanical-biological treatment. The first phase of the latter separates the dry fraction (paper, glass, aluminum) from the wet one. The second one combines an anaerobic and composting process. The selection aims to identify all the materials that can be recovered and those that can be sent for energy recovery (solid recovered fuel, SRF). In the diagram below the percentages of undifferentiated fraction sent for recycling are made available.

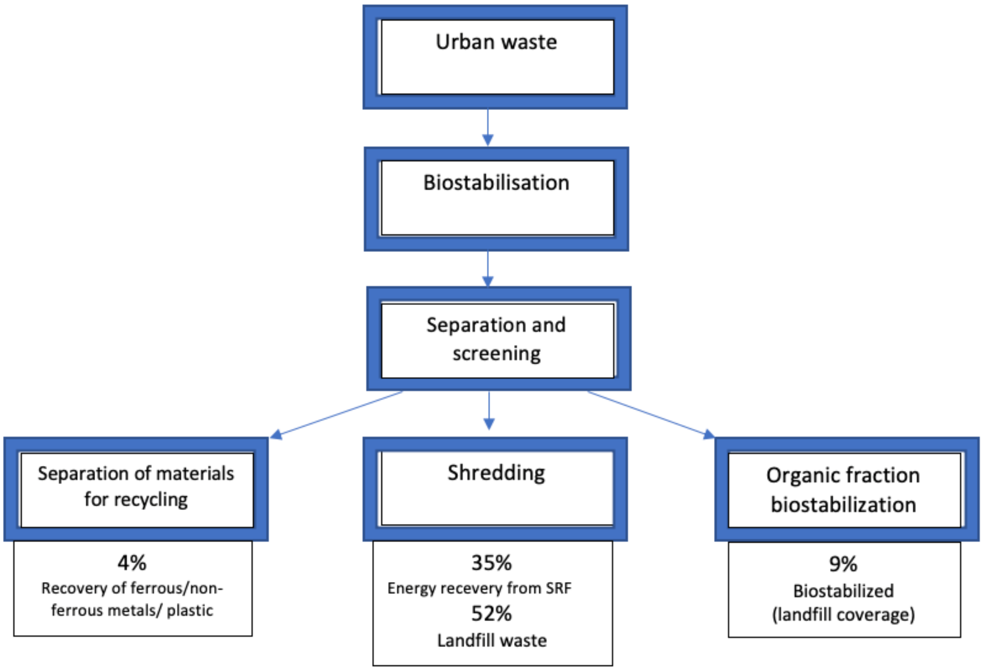

Figure 1.6 Urban waste stream in mechanical-biological treatment

These percentages refer to a total of 9.5 million waste, screened through a panel of 130 plants. A large percentage of the waste sorted by landfills derives from waste management activities and is therefore special waste.

Landfill waste is deposited in the subsoil and covered with a dry organic layer. Waste degradation leads to the production of leachate and biogas. Being the biogas composed of methane, a gas that contributes to global warming due to the greenhouse effect, it is possible to set up collection systems suitable for the recovery of biogas, which can be processed by biomethane for transport[3].

1.7 Recycling

Recycling is the activity closest to the concepts of the circular economy, achieved through the use of about 7,200 plants and generating almost 135,000 jobs.

Table 1.1 Digestion plants distribution in Italy [1.7]

Geographic Area	# Production plants	Employees
Nord-West	2.309	40.370
Nord—East	1.763	36.519
Center	1.365	20.555
South and islands	1.756	35.882
Italy	7.193	133.326

Every year the recycling centers process 108 million tons of waste, deriving from separate collection and from special waste. In particular, 49% of urban waste and 65% of special waste are shipped.

The recycling of the organic, which will be deepened in the next paragraphs, begins with the collection and the transport in special plants called digesters and composting.

1.8 The Composting and Anaerobic Digestion plants in Italy

The production of soil improvers and biogas through biotechnological processes receives special waste from industry and urban waste:

- The wet fraction deriving from urban solid waste (OFMSW), which constitutes 30 to 40% by weight of urban waste [1.3]
- Agricultural production waste, ie organic waste that coincides with stems, leaves and cereals. They are collected only from the maintenance of the green between 15 and 90 kg / inhabitants / year only in Lombardy, Veneto and Piedmont [1.5]
- Waste from industrial production, coming from both animal and vegetable waste. For example, from the production of oil, inedible fruit and vegetable peels, meat processing wastes, milk and dairy products.
- Sludge, deriving from the purification of civil and industrial waters.

[3] For example, HeraAmbiente, a company operating in the north of Italy in the field of the circular economy, produces biogas purified biogas which, re-injected into the network in the form of bio-CNG (compressed natural gas) feeds public transport.

The four types of waste mentioned above, after being collected, are accumulated in digestion plants. The latter support an aerobic or anaerobic process: both have the final aim of bringing the materials in input into a more stable, non-putrescible form. The two processes are very different from each other and consequently so are the final products derived from them, even if the input waste materials can be the same. The aerobic process is carried out in the open air through the use of insufflate tanks of air, to favor the exchange of oxygen. The ultimate goal here is to produce quality compost that is used in agriculture. On the contrary, the anaerobic process is carried out indoors and in a warm environment, producing both biogas and compost.
The absence of oxygen in the anaerobic process makes the plant easier to implement than the corresponding aerobic with low initial costs and high maintenance costs. Moreover the anaerobic process refuses difficult to manage and control due to the temperature that must remain at an average of 55 ° C to allow thermophilic bacteria to operate. Instead, the aerobic process is often operated in open-air tanks, but the continuous need for air makes the investment in the plant rather expensive, but simple to control [1.6].
Currently in Italy there are 340 plants:

Table 1.2 Number of digestion plants in Italy [1.3]

Plant type	Quantity of plants	Tons*1000 of OFMSW
Composting	285	3259
Anaerobic/aerobic integrated	31	2356
Exclusively aerobic	24	288
	340	5903

As can be seen from the data in the table, in Italy there are many composting plants even if they are small. In fact the latter treat about 12 * 10^3 t of waste per year. The same is true for anaerobic implants, which are fewer in number. On the other hand, the situation changes as regards anaerobic / aerobic plants, which process on average 76 * 103 t of OFMSW per year.

1.9 Encouraging the Potential of Anaerobic Digestion Plants

The preceding paragraphs have emphasized how the number of anaerobic digestion plants is proliferating in Italy. Despite this, the main products of these plants are biogas and compost, used respectively for the production of electricity, heat and fertilizers. Biomethane is a product of subsequent processing, in fact it derives from the upgrading of biogas from which impurities and a significant percentage of CO2 are removed. In fact, the biomethane supply chain in Italy includes gas compression but not liquefaction, which results in LNG (Liquefied Natural Gas). This fuel is becoming increasingly popular as a form of alternative fuel to diesel for industrial transport vehicles, such as trucks and ships. The absence of systems for liquefaction of methane forces companies and transporters to turn to the foreign market. A serious logistical gap that has a significant impact on purchase prices, on which transport costs weigh heavily (the load bases most used by Italian users are in Spain, France and the Netherlands). As a result, there is an LNG market completely covered by

imports, despite the presence in Italy of numerous biomethane production plants that could cover the demand through liquefactors at least partially: it is estimated that Italy will be able to produce 8 billion m3 of its own [1.8] on an annual basis, corresponding to 10% of the national requirement.
It is clear that the choice to invest in a developing market such as biomethane leads to risks that individuals and companies must face:

- The amount of investment to enter the market
- High competition with natural gas imported from abroad at low cost
- The disorganization of the administrations in terms of waste collection: it is in fact sufficient to analyze the disparity of waste collected between regions of Italy. In particular, in 2017 northern Italy recorded 66.2% of differentiated waste, unlike the center which touches 51.8% and the south 41.9% [ispra database]. This fact directly influences the supply of FORSU of the anaerobic production plants.
- Lack of coordination of the different political bodies.

The problem was partially solved in 2013 through the publication of the Decree of 5 December 2013, unblocking the incentives for those who show that they want to invest in the sector. However, these incentives were only finalized in 2018, through the decree of 2 March which provides funds for 4.7 billion euros for all biomethane installations built or to be built by 2022. Biomethane producers enjoy the advantages conferred from the issue of Consumption Release Certificates (CIC), which provide for a fee of € 375 for every 10 Gcal of biofuel placed on the market.

1.10 Sector Issues

The future of the fuel market has reached a turning point and thanks to the long chain generated by biomethane, we could arrive at a real alternative to more polluting fuels. Waste collection is only a small piece of the circular economy mosaic, but of fundamental importance since it coincides with the starting point. Consequently, an error in this phase leads to the propagation of problems in an accentuated manner with the protracted process. To date, in fact, various problems have been encountered and from different points of view. In particular, dealing with the production of biogas, there are numerous difficulties in closing the process generated by the circular economy. Furthermore, it is a business model that, to generate social utility, must be applied continuously by the various actors, who must be involved in all the various phases. Consequently it is necessary to evaluate the chain as a whole, so that no actor has a negative impact on another.
Furthermore, the political / administrative horizon itself is not clear on the subject. This is true due to the lack of coordination between the various bodies and the regulatory framework that regulated the incentives only in 2018 when 28 production plants had already been built.

1.10.1 Lack of Recycling Facilities

The Italian situation is in a situation where the collected waste, even differentiated, does not undergo a recovery treatment due to the absence of the assigned plant. This has repercussions that impact both on the few plants present in Italy in terms of excessive storage and on the export of waste. Indeed, Italy is forced to export 3.5 million tons of waste for a value of 250 million euros [1.3] [1.9]. In particular, Italian waste supplies waste-to-energy plants and incinerators throughout Europe, particularly those in Germany. In reality, China also imports a lot of waste, especially from Europe and the US [source?], So much so as to publish a tender with the aim of reducing the quantity and type of waste imported and this event has only increased the phenomenon of illegality in the sector.
From the point of view of the international waste trade, having the possibility of increasing the number of recycling plants, the option to import goods instead of exporting them is attractive for all the products that can be resold.

1.11 Conclusions

The waste collection chain and the state of the art of anaerobic digestion taken into consideration represent a critical situation that has economic and social repercussions. The potential hidden by the waste supply chain is reflected in the number of plants involved in their treatment, which expands like an oil stain. Nevertheless, from the data previously reported regarding waste deposited in landfills, there are no specific recovery processes for many types of waste and “end of waste” criteria. This represents an opportunity for entrepreneurship, intent on exploiting resources efficiently by also aiming at a partial energy independence.
To develop a healthy business it is necessary to reduce the administrative barriers that hold back investments and increase uncertainty rather than reduce it. Recycling therefore generates a market that is supported neither by the state of today's economy nor by the tendency of consumers to purchase virgin raw materials rather than secondary raw materials. Furthermore, the lack of recovery processes themselves negates the possibility of generating a market, due to the lack of production of the second raw material.
Therefore, some bureaucratic initiatives are needed to aim to replace raw materials:

- To encourage the purchase of goods produced through recovery through tax relief and VAT restructuring. These measures can be implemented for an initial period of introduction.
- Develop new technologies in compliance with minimum environmental criteria to develop additional services to support recycled products
- Introduce minimum percentages of recyclate of which the new products must be composed. In this regard, the European commission has proposed the use of recycled plastic in the production of bottles for at least 30%.

In this historic moment, China, which turned out to be the largest importer of waste until 2018, has begun to bind this custom. Italy therefore has the opportunity to develop regulations and technologies to stimulate the recycling market. This refers to the entire chain that recycling generates, but also to the biogas sector, which is one of the many products from the circular economy.

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Chapter 2

Biomethane Production

Thanks to the growing political attention to renewable energy, the possibility of exploiting the energy value of FORSU for the production of biogas, biomethane and compost, concepts analyzed in the first chapter, was evaluated.
In a context of extreme and continuous energy need and high environmental risk, anaerobic treatment with recovery of the biogas produced is today a system of great interest.
The following chapter intends to study the construction of a biomass treatment plant through anaerobic digestion, which in turn aims to pursue the following objectives:

- Energy recovery: the anaerobic treatment under controlled conditions leads to the degradation of the organic substance and the production of biogas that will be used in the upgrading section to produce biomethane.
- Reduction of CO_2 emissions: this reduction is attributable both to fermentation in a confined environment and to the use of biomethane as a motor fuel to replace traditional fuels.

2.1 Notes on Anaerobic Digestion

The microbial decomposition of organic residues in an anaerobic environment is a process that occurs spontaneously in nature. In order for the digestion process to take place, it is necessary to act on different groups of microorganisms capable of transforming the organic substance into intermediate compounds, mainly acetic acid, carbon dioxide and hydrogen, which can be used by methanogenic microorganisms that conclude the process producing methane.
Anaerobic digestion can be divided into four stages [2.1]:

- Hydrolysis, where organic molecules undergo cleavage in simpler compounds such as monosaccharides, amino acids and fatty acids.
- Acidogenesis, where further splitting occurs in even simpler molecules such as volatile fatty acids (for example acetic, propionic, butyric and valeric acid), with production of ammonia, carbon dioxide and hydrogen sulphide as by-products.
- Acetogenesis, where the simple molecules produced in the previous stage are further digested producing carbon dioxide, hydrogen and mainly acetic acid.
- Methanogenesis, with production of methane, carbon dioxide and water.

Anaerobic digestion can be performed either wet or dry. Dry digestion refers to mixtures of material with minimum solids content of 30%, while wet digestion refers to mixtures with a minimum of 15% solids content [2.2].

2.2 Plant Types

Conventionally, depending on the type of bacteria used, there are three different temperature ranges in which anaerobic digestion is conducted:

- With simplified systems it is possible to work in psychrophilia (10-25 ° C);
- With mesophilic bacteria working at temperatures between 20-45 ° C, with an optimal range of 37-41 ° C;
- With thermophilic bacteria the optimal operating conditions imply a temperature range between 50-52 ° C, with temperatures that can also be relatively high and exceed 70 ° C.

The principle used for the dimensioning of anaerobic digesters is based on the need to ensure a residence time of suspended solids (SRT - solid retention time) inside a complete mixing compartment, high enough to guarantee a consistent degree of removal of the volatile part. The residence time in a digester therefore varies according to the quantity of material to be treated, the type of material and the operating temperature. Another particularly important parameter is the pH value. In the case of digestion conducted with mesophilic bacteria, the residence time is between 15 and 30 days. In the case of a process with thermophilic bacteria, higher temperatures allow for faster digestion, requiring only

two weeks to complete. On the other hand thermophilic digestion has a higher cost, requires more energy and is more critical than the similar mesophilic process. Despite this, the latter is currently the most used.
Psychrophilic digestion requires residence times of more than 40 days, up to a maximum of 90 days.
Continuous digesters have mechanical or hydraulic devices to mix the material and continuously extract the excesses to maintain a reasonably constant volume, during the continuous addition of organic material. The other typology of digesters is the discontinuous batch, simpler in its structure but which has the disadvantage of emitting odors and possessing problematic emptying cycles: once the initial feeding has taken place the reactor is closed and on the whole mass treated does not act any device of sorts for the whole duration of the process [2.3] [2.4].

2.3 General Illustration of the Project

The material that feeds the plant consists of organic substances that can be anaerobically degraded to produce biogas and then biomethane.
The plant in question will be built with the aim of enhancing waste and will be able to produce biogas starting from the Organic Fraction of Urban Solid Waste (FORSU).
The description is based on the production plant of CTIP BLU srl in the authorization phase, in the municipality of Mosciano Sant'Angelo (TE). By adopting the principles of the circular economy, the plant foresees the production of biomethane and compost.
The plant receives 40,000 t / year of FORSU and 8,000 t / year of green as input, which through the processes below produces biomethane and compost according to the diagram below:

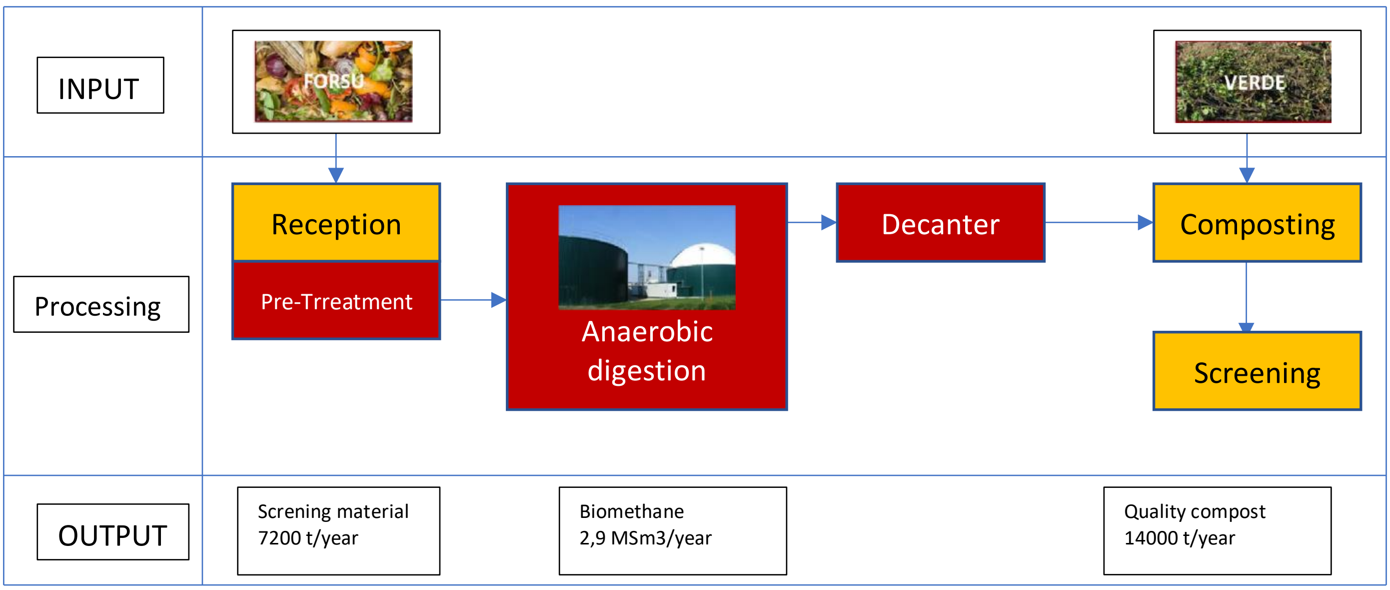


Figure 2.1 *Input/output flow, CTIP BLU srl plant*

The plant uses a wet technology ("WET"), in which the biomass in digestion has a dry organic substance content of less than 10%.

The quality of the biomethane produced complies with the UNI / TR 11537 standard and complies with the SNAM specifications, so that it can be reintroduced into the network or used as an advanced biofuel for transport.

2.4 Pre-Treatment

FORSU and other biodegradable wastes are transported to the plant through special vehicles that unload the arrays in question in a building dedicated to the reception of the same.

The entire area of the building used for reception, putting the FORSU in reserve and pressing, is kept in depression and the extracted air is conveyed to a bio-filter. The transfer of biomass takes place directly in the material accumulation pit, shown in figure 2.3 (section A). The pit also takes on the function of storing the daily and weekend accumulation of all incoming materials, in order to guarantee a continuous supply of biomass to the digester and therefore a regular production of gas.

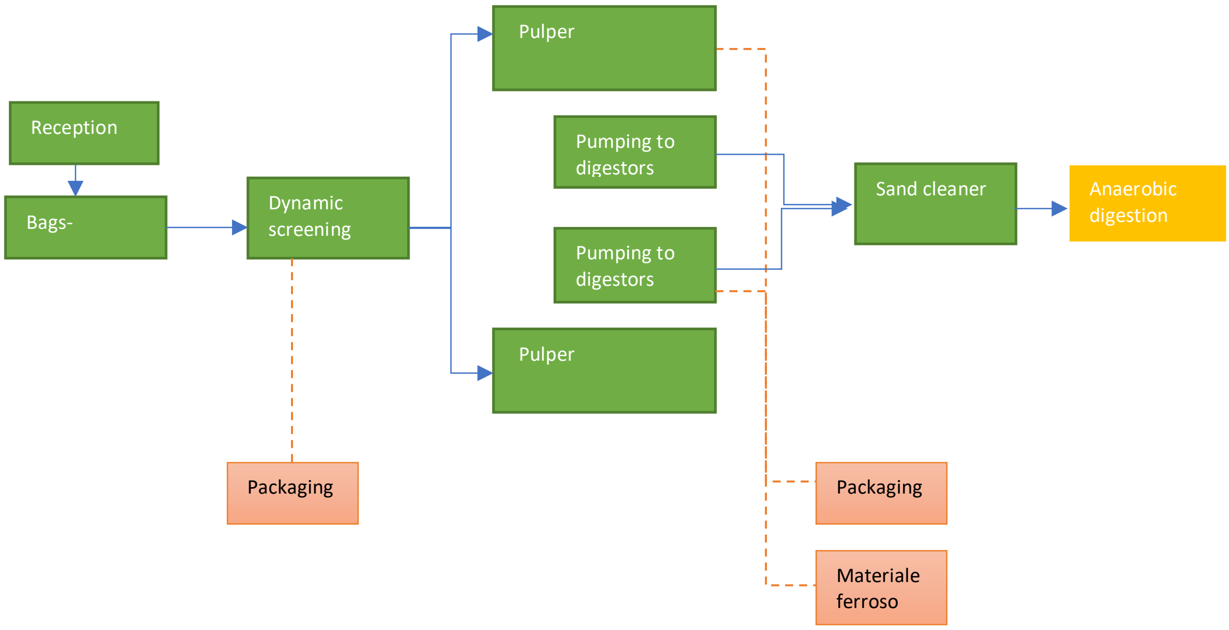


Figure 1.2 *Pre-treatment operation scheme*

2.4.1 Plant Configuration

As described in the previous paragraph the FORSU is transported in section A, which shows the interior of the building used for pretreatment. The trucks enter the M31 unloading area kept in depression and the organic fraction is then deposited in the M32 and M33 pits. The maximum volume of matrices placed in the reserve amounts to 600 m3, divided into 2 tanks in a compartment with the planimetric dimensions of about 15 x 12.5 m.

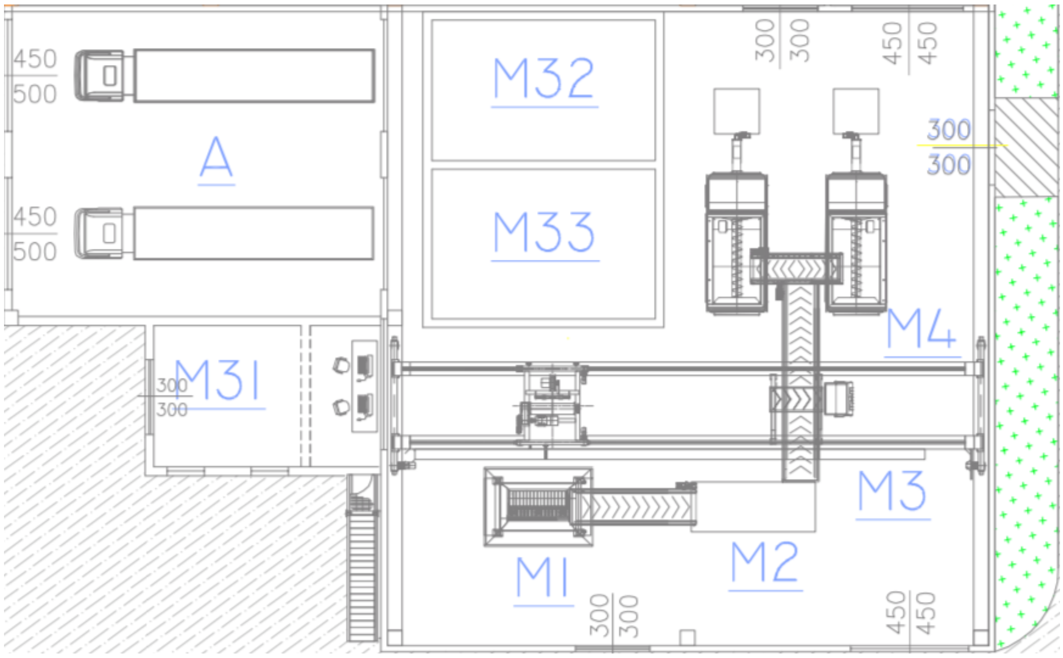


Figure 2.3 Pre-tratment layout

This phase of pre-treatment of the matrices will take place by means of a system, applied in the treatment of wet waste, designed to divide the organic substance from the inorganic, then physically separating any non-organic materials present in the FORSU (plastic, stones, etc.).
The materials obtained with the use of this system are:

- A puree, which is destined for the next phase of anaerobic digestion.
- A dry part (overgrowth) composed of fibrous material and plastics.

The bucket overhead crane transfers the load to be processed in the next pre-treatment phase.
In particular, the accumulated staff faces the following process in sequence:

- Bags-Breaker (M1), which allows the opening and emptying of the bags through the use of combs;
- Dynamic screen (M2), is made up of a series of superposed rollers and disks to separate the slag or to divide the elements according to the size. The smallest and lightest fraction falls by gravity in a container below the machinery, while the heaviest and largest in size is transported by the rollers at the end of the run and therefore towards the exit;
- Iron remover (M3), for removing ferrous pieces;
- Squeezers (M4), the load processed so far, of a still rough matrix, is made homogeneous by the squeezers that carry out a material pulping process. In output are obtained unwanted waste and puree which is mixed together with process water.

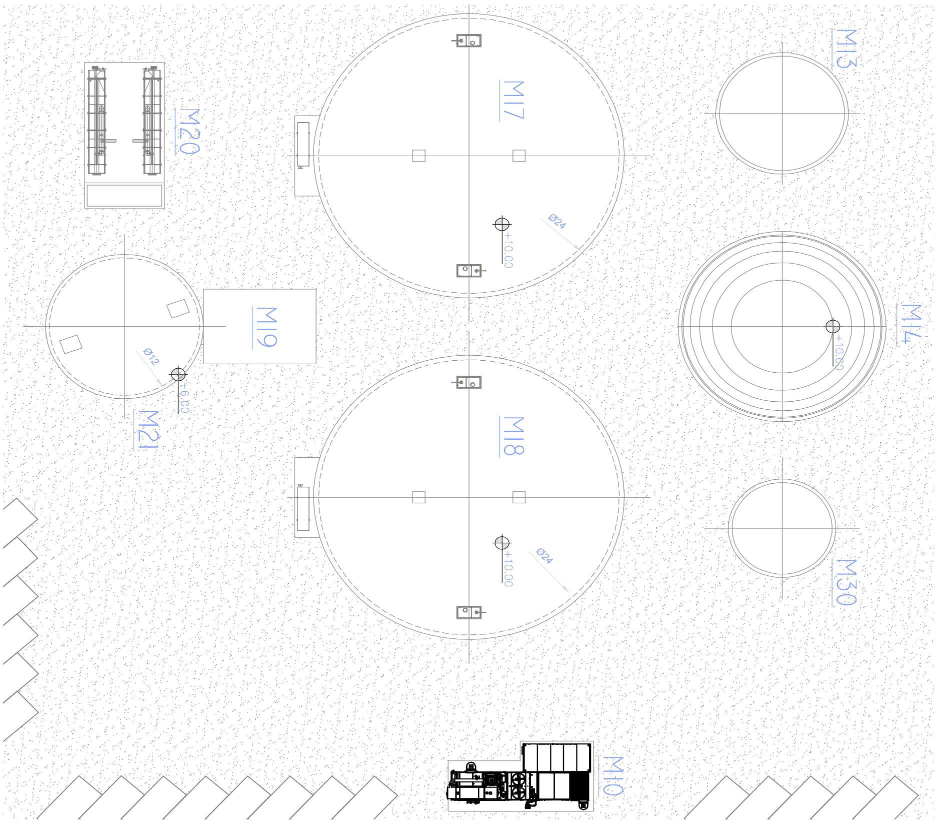
All waste materials, which mainly coincide with ferrous particles, plastic and glass, follow a bio-drying process on site before being sent back to the respective recycling process. Moreover the air sucked in this section is reused in the aerobic phase in the composting process. The purée instead, before being sent to the digester is sent to a grit chamber (M20), which is physically located near the digesters, outside the pretreatment area. In fact, through this last machine the pretreatment ends, with the removal of small solid materials (glass, crushed stone, sand, etc.). Materials with low density and therefore floating are foamed and removed, always from the same machinery. A booster pump then sends the puree into a pre-tank (M21).

2.5 Anaerobic Digestion

The degradation of biomass by microorganisms kept in anaerobic conditions takes place in the anaerobic digester and is carried out under thermophilic conditions: in particular, a temperature set of 50-55 ° C is provided.
The anaerobic digestion phase was sized considering the SRT (Solid Retention Time) value of 30-40 days.
In the current configuration, two representative scenarios can be presented:
1) WORST CASE: which represents the start-up phase (plant and recycling), where the quality of the FORSU will have product characteristics with a high presence of unwanted material (eg 18%), with a production of biomethane of around 350 Sm^3 / h;
2) BEST CASE: in which the treated quantity equal to 40,000 t / year, with a lower quantity of unwanted (eg 10%), will develop a production of biomethane equal to 390 Sm^3/h.

2.5.1 Plant Configuration

The purée, after having been processed inside the sedimentation basin (M20), is sent inside a pre-tank (M21) which has the role of buffer. Moreover, the puree is heated by a gas boiler (M19) in order to keep the environment inside the digesters at the correct temperature to operate in thermophilic conditions.
The so heated puree is introduced through a pump in the two digesters (M17 and M18). Here is the degradation of biomass and the production of biogas.
Digestate and biogas are subsequently sent to a storage tank (M14). From here, the biogas produced is sent to the upgrading process, while the digestate is transferred to an area of the plant where it will undergo a composting process.



Figur3 2.4 Anaerobic digestion layout

2.5.2 Heat Exchanger

Since the ideal working temperature inside the digesters will be around 55 ° C, a heat exchanger (M19) has been installed for both tube type digesters with circulation of the primary digestate in the inner tubes and water warm on the outside. To heat the exchangers, the cooling water of the internal combustion engines of the cogeneration unit is used. The arrival temperature of the water is 90 ° C for any additions there is a natural gas / biomass boiler for the integration of thermal energy.

2.5.3 Anaerobic Digestor

The mix of organic matrices mixed and homogenized by the substrate preparation and aggregate separation system is sent to anaerobic digestion. The anaerobic digestion section consists of two primary digesters (M17 and M18) and a cold storage digester (M14).
In the primary digesters the degradation of the organic substance and the production of biogas takes place under controlled mixing and temperature conditions. In the second one the storage of the primary digestate produced by the anaerobic digester takes place and at the same time the accumulation of biogas in the overlying pressostatic low pressure accumulator.
The mixing of the primary digestate in the digesters is ensured by special lateral stirrers specifically sized to ensure adequate handling of the liquid mass. The digestate obtained is subsequently sent to a storage tank that acts both as a lung of the digestate itself and as a

biogas accumulator. In particular, the accumulation of biogas takes place thanks to a gasometer placed above the tank (M14).
The digestate is instead sent in M13 where it undergoes a process of separation of the liquid and solid fraction. In particular, the solid fraction is sent to composting.

2.6 Upgrading

The biogas produced by the FORSU anaerobic process is conveyed in a constant pressure pipe and sent, after passing through a treatment system, to the upgrading group.
This process consists of a first pre-conditioning phase by which water and particulate matter are eliminated from the gas flow, condensing the incoming gas. A compression of the biogas follows so that it can cross the membranes, to separate the CH4 methane from CO2, H2O and H2S.
The biogas accumulated in the gasometer is in fact sent to a condensation removal filter. The gas is then analyzed and purified by H2S hydrogen sulphide via a biological chemical process. The biogas from fermentation processes is in fact generated with the presence of impurities such as reduced organic compounds, H2S and humidity. The purified biogas cannot undergo an upgrading process until it reaches the minimum purity values required by the upgrading process itself.

2.6.1 Plant Configuration

From the M14 storage tank, the biogas is stored in the gasometer located above the tank itself. The gasometer is connected to the biogas line which is taken to M15 where it is purified by H2S sulfuric acid. Finally we proceed with the upgrading process in M8. Biomethane is finally ready to be placed on the net or sold as fuel.

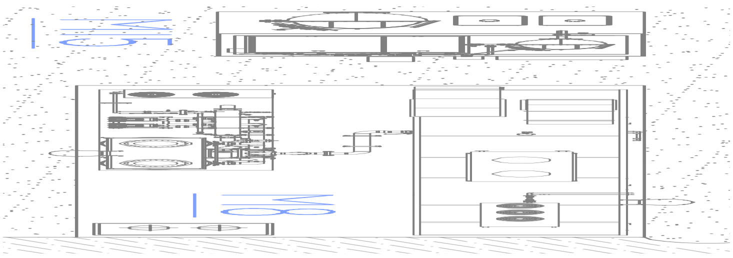


Figure 2.5 Upgrading section layout

2.6.2 Biogas Line

The biogas produced by the FORSU anaerobic process is conveyed in a constant pressure pipe and sent, after passing through a treatment system, to the upgrading group.
The biogas accumulated in the gasometer is in fact sent to a gravel filter to remove the foam, allowing condensation to escape. Then the gas is analyzed and purified by H2S sulphidic acid with a first desulfurization process, (another will follow in the upgrading phase).

For the above considerations, before using the biogas in the next section, it will be purified within a specific treatment section consisting of two basic washing towers.
Any excess biogas that, for various reasons, could not be started in the next section or the biogas produced during system shutdown periods will be burned in a special safety torch.

2.6.3 Biogas Upgrading

The previously filtered and dried biogas enters a second activated carbon desulfurization system, where the H2S still present will be removed.
Subsequently the partially purified biogas is compressed, before entering a scrubber for washing to remove the ammonia.
At the end of the scrubber, the biogas is still rich in water and carbon dioxide: in these conditions the gas enters the membranes for final depuration. At this point the biogas is already biomethane, and is compressed for vehicular refueling or the introduction into the network.

2.7 Output: Biomethane

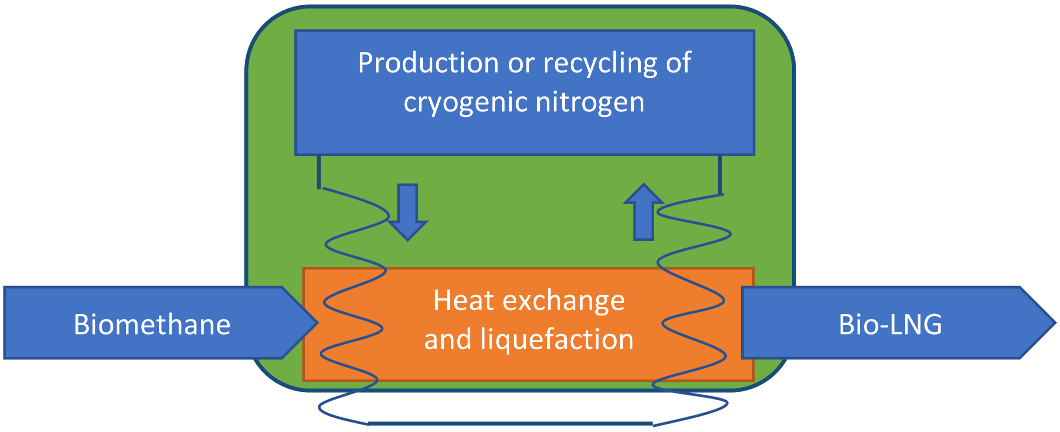
The table below shows the expected values of biomethane production:

	Biomethane	
Annual operation in hours	8.300	h/y
Nominal production	333	Nm3/h
Annual nominal production	2.938.200	Sm3/h
Max production	366	Nm3/h
Max production	386	Sm3/h
Max annual production	3.203.800	Sm3/h

2.8 Liquefaction

The considered plant feeds biomethane directly into the network. Here we consider the hypothesis of liquefying the biomethane produced with the objective of producing bio-LNG, through an economic evaluation. This analysis is detailed in chapter 5.
The liquefaction technology, which allows to reduce the specific volume of the gas by about 600 times compared to standard conditions, allows the storage and transport of considerable quantities of energy in considerably reduced spaces at competitive costs [2.5].
The liquefier allows, through heat exchange between the biomethane and an inert fluid (liquid nitrogen) to lower the temperature of the gas and liquefy it.
The liquefaction can therefore take place in two ways:

- by exploiting the frigories obtained from the evaporation of liquid nitrogen;
- through a heat exchange integrated in a nitrogen recycling liquefaction cycle, including compressors and expansion turbines;


Production or recycling of cryogenic nitrogen
Biomethane
Heat exchange and liquefaction
Bio-LNG

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Chapter 3

GNL and Bio-GNL Logistic

GNL stands for Liquefied Natural Gas. It is a gas composed mainly of methane, the simplest and most abundant hydrocarbon in nature: one carbon atom and four hydrogen. After extraction and elimination of the impurity it is cooled to -162 ° C, a temperature at which it passes from the gaseous state (CNG) to the liquid state (LNG), reducing its volume by 600 times. Furthermore, it is possible to make a distinction between LNG and bio-LNG. The first is transported by methane tankers from the extraction points and is an energy source of fossil origin. The second is obtained from the liquefaction of biomethane, although it may contain traces of natural gas.

Today the use of LNG for heavy duty vehicles is developing strongly in Europe, thanks to the launch of new, more efficient vehicles and the increasingly widespread distribution infrastructures. Bio-LNG therefore represents a short-term solution as a sustainable fuel to replace fossil fuels such as diesel, allowing the reduction of greenhouse gas, NOx and fine dust emissions. Furthermore, bio-LNG can be stored and transported easily, which allows projects to be produced for biomethane production, especially if the gas network is remote or has limited capacity. Often, in Italy, difficulties are encountered due to the distances connected, to the limited capacities of the distribution network, to the supply pressure to be reached when it comes to the transport network, to long times for permits and connection from which the Bio-LNG allows you to free yourself.

With the increase in LNG consumption for transport and with around 1300 municipalities outside the national gas network, LNG demand in the future will increase significantly. Bio-LNG therefore offers an innovative response to the three main challenges faced by our society, namely climate change, air pollution and energy dependence issues.

3.1 LNG Foundations

Today, LNG is one of the most attractive solutions on the market to meet the environmental constraints imposed by the European Union. Furthermore, it is an easily achievable solution, since there are technologies to support this supply chain.

The trucking fuel market is therefore slowly changing direction. This is due to reasons that have foundations in politics, in economic convenience as well as in the environment. In fact, we have to do with a clean fuel that undergoes purification processes before being liquefied and distributed. The reduced sale price of the LNG, on which at the moment there are no particular national excise duties, also makes it more convenient to purchase a truck with a gas combustion engine rather than a diesel one. To all this it must be added that politics for some years now increasingly directs demand, also through ad hoc incentives, towards vehicles that are not diesel; in increasingly common Italians, shrinking ordinances are being adopted that prohibit the entry of such vehicles into city centers.

3.1.1 A Clean Fuel

The environmental value of LNG is mainly determined by the molecular simplicity of the product, which allows clean combustion with very low solid residues, and its compositional characteristics, which make it a clean fuel free of sulfur. In fact, it has a lower carbon content compared to coal and oil and emits a lower quantity of greenhouse gases in the combustion process. Therefore, the use of natural gas limits CO2 emissions compared to other fossil fuels. In fact, carbon dioxide savings are 60% compared to coal per unit of energy used while 20% compared to oil [3.1]. But natural gas also has lower emissions of nitrogen oxide (which contributes to the acidification and formation of ozone at the surface level) and sulfur dioxide (with nitrogen oxide, determines acid rain and the formation of particulates that are among the causes of smog and poor air quality).

The effectiveness of the use of LNG for the purpose of reducing the emission of greenhouse gases into the atmosphere depends on the technological solutions adopted with regard to motorization and on the range of measures identified to reduce any unwanted releases of methane, together with the management systems of the Boil-off vapors.

3.1.2 An Economic Fuel

LNG is a fuel whose objective is to replace diesel in the automotive market. This ambitious goal can also be achieved thanks to the opportunity in terms of convenience that the LNG represents. In fact, taking into account the average cost of fuel, the average cost of Diesel stands at € 1.45 / l [3.2] unlike LNG, which is still at € 0.97 / l [3.3]. This obvious price difference acquires even more value if it is contextualized in terms of savings of trucks that travel more than 100,000 km a year, with a useful life of one million km. Furthermore, the price of LNG is set to decrease: as the number of service stations increases, competitiveness between suppliers will increase.

Another aspect is related to price stability [3.4]: while that of Diesel is influenced by political factors in the countries of origin, the price of LNG is rather stable since it comes from countries that do not suffer from these problems. In particular, there is a stock index for natural gas, but since LNG is sold as fuel, the pricing system was linked to that of the price per barrel of oil. Recently, on the other hand, it was decided to specifically consider different stock market indices, such as the coal market index [3.5].

3.1.3 Diesel Ban

At European level England and France are the most determined members to completely abolish the circulation of diesel vehicles on the roads by 2040. In Italy, on the other hand, the Ministry of Infrastructure and Transport does not consider the pollution class of a vehicle, but only checks that all the components installed on board are approved and comply with the highway code. This, together with the absence of a real national directive, allows each individual municipality to choose for which type of car to be barred from circulation, when and for how long.
Currently the diesel block is valid only for the city center (Florence, Naples, Bologna, Milan, Turin, Rome, Bari) and the prohibitions vary depending on the municipality. Considering the trucks, the problem does not arise because their handling takes place mainly between industrial areas outside the cities. Nevertheless, the decision of one of the members to prohibit the passage of diesel vehicles or trucks on motorways would affect all hauliers of goods in the rest of Europe. Transportation companies and multinationals whose trucks are transporting internationally would find themselves having to convert (within a few years) entire fleets to alternative fuels.
In view of the information provided above, the road haulage market has evolved in recent years. Indeed, in March 2019 there were 143 new registrations of trucks (with total ground weight over 3,500 kg) fueled with liquid methane, with an increase of 83.3% compared to the same month of the year 2018 (+65 units). In the first quarter, the new LNG trucks numbered 336 compared to the 161 in the same period in 2018. These results actually represent an increase in contrast with the overall heavy vehicle market, which recorded a slowdown of 11.5% in March (to 2,084 units) and 11.4% in the three months (to 6,161 units). The latter negative trend was probably highlighted due to the end of the 2018/2019 incentive policy for trucking companies, with the consequent market blockage evident.
As far as diesel trucks are concerned, registrations are down 15.8% to 1,881 units (-15.3% to 5,683 in the quarter), CNG grows by 67.6% to 57 units (+ 140% in the quarter to 132 unit), the diesel / electric hybrid drops from 6 to 3 units (from 21 to 6 in the quarter). No registration in the month for electric trucks (from 2 to 4 in the quarter) and petrol (zero from the beginning of the year, compared to 4 in the first quarter of 2018). The share of alternative vehicles therefore rises close to 8% and today there are about 1,440 LNG trucks circulating in Italy [3.6].

3.1.4 Infrastructure

The presence of an adequate infrastructure generates a network externality that allows to increase the size of the transport LNG market ever faster. In particular, the increase in LNG vehicles on the roads would lead to greater network capillarity, which in turn would increase the number of customers interested in LNG.
Furthermore, the success of an alternative fuel is not only based on efficiency, economy and low environmental impact compared to traditional fuels. A key element is the actual availability and availability of the fuel. Logistics plays a decisive role in this regard for the affirmation of this fuel on a large scale.
As for LNG for road transport, the situation is still evolving. The still limited presence of filling stations does not allow a homogeneous coverage on the whole Italian territory, with an evident imbalance as regards the southern regions. However, the number of refueling points is constantly growing.
In Italy there are 55 road systems, a number that puts Italy at the top in Europe. There are also solutions such as distributors, methane to gaseous to liquid state converters built within the same transport companies, if the size of the fleet allows it. To date, LNG arrives in Italy by road and rail, coming from three large storage centers in Barcelona, Marseille and Rotterdam. To avoid the use of excessively distant terminals, two storage points (small scale) will be put into operation in Livorno and Ravenna, which will make it cheaper to distribute the LNG throughout the Italian territory, reaching more widely also the south. In Europe, a fairly widespread network of LNG plants, as well as in Italy, is found in Spain, France, the Netherlands, to a lesser extent in Great Britain.
In total the overall network counts on just under 200 stations in sixteen countries, including Turkey, but the number is growing regularly at short intervals. One of the key countries for European freight transport, Germany, had only three plants until 2018, one in Hamburg, one in Berlin and one between Stuttgart and Frankfurt. The decision of the German Government to exempt from the payment of the MAUT (motorway toll) the ecological heavy vehicles also to LNG could however push for a rapid change, with the creation of a distribution network of LNG appropriate to the size of the German territory. As for the growth in the number of LNG trucks, the Natural and Biogas Vehicle Association, NGVA Europe, expects to reach 300,000 vehicles in the year 2030.
In terms of infrastructure, it is necessary to take into account the approximately 1,500 Italian production plants, located mainly on farms and farms, capable of producing over two billion cubic meters of biogas, currently used for electricity generation. A slice of this biogas could be pumped into the tanks of LNG trucks, after appropriate liquefaction.

3.2 GNL Demand

By virtue of the aforementioned characteristics, the LNG is therefore particularly suitable, in particular, for being used as fuel in the maritime transport sector and in heavy road transport.
Unlike what happens with light road transport, in this sector the diffusion of LNG is favored by the fact that this represents, to date, the only fuel capable of guaranteeing high mileage autonomy, indispensable for covering long characteristic distances of this type of transport,

and, at the same time, a volumetric bulk of the tanks compatible with the means on the market.
The National Strategic Framework has predicted that the sector will reach an annual demand of 400,000 tons by 2020 and then increase to 1,250,000 tons by 2025 and reach 2,500,000 tons in 2030.
A further use of LNG as a fuel is in the maritime transport sector: in the last few years, this sector has been particularly interested in the subject of LNG, since from 1 January 2020 the provision of the IMO (International Maritime Organization) will come into force which sets a roof with a sulfur content of 0.5% for marine fuels. Among the ways to comply with this provision, the use of fuel oil or low-sulfur diesel (BTZ), the use of scrubbers to reduce emissions of sulfur oxides from the fumes or precisely the use of LNG. Despite this, the option of using LNG cannot rely on an already consolidated logistics, which is still the subject of infrastructure investments aimed at guaranteeing the availability of the product at the naval and land supply points.
However, the use of LNG as a marine fuel is certainly a choice that is well suited to the characteristics of new ships and that, if the chain is properly developed, will allow Italy, also thanks to its strategic geographical position for the naval traffic, both commercial and civil, in the Mediterranean Sea, to be considered a hub for supplying the sector. Estimates of the National Strategic Framework forecast a 2025 demand of 800,000 tons and 1,000,000 tons by 2030, but given the above this demand could reach higher levels.

3.3 GNL Logistic

Following the investments made in Italy to create an advanced network for gas distribution, heating and cooking, public bodies and governments have established links with other countries for supply. In particular:

- An Italian leading actor has been created: ENI;
- The supply sources, the Italian wells, the supply from Algeria, the connection with Russia with a network of pipelines connected to the Italian market were defined and connected;
- A maritime entrance door has been defined with the Panigaglia regasification terminal;
- A security and emergency system was built with strategic storage facilities;
- A national distribution network was established, the Snam network, which allowed the connection of primary users, city distribution networks and vehicle distributors.

For the LNG instead, we started from the end users. Visionary entrepreneurs interested in reducing the ecological footprint of transport bought LNG-powered trucks around the first installed distributor; others have instead dealt with production. The increase in demand has created the conditions for the diffusion of other distributors, above all independent operators, made with refueling by tankers from the supply points in Barcelona and Marseille.

This explains the very low number of distribution points in the south where the excessive distance from the loading bases adds transport costs which, once translated to the final sales price to the hauler, make this type of feed less convenient. There is therefore an audience of users, a network of distributors, but it seems to lack a real strategic plan to ensure the LNG supply chain.
It should be noted that the two major regasification plants in the country were built with off-shore solutions that do not include the arrival of LNG at the coast as it is, through transfers on ships, but only of regasified methane. In March 2019, OLT announced the start of authorization procedures for the necessary changes, envisaging being able to supply LNG to tankers to bring it to the ground or supply other ships.
Even the marine system is studying the use of LNG for the supply of ships on the quay or for the production on land with gas turbine plants of the electricity needed for the ships in port.

3.3.1 Small Scale LNG

The "Small Scale LNG" (or SSLNG) is defined as the mode through which the LNG is managed in small / medium quantities directly in liquid form. In particular, the expression SSLNG is used to distinguish activities related to the transport, distribution and supply of small-scale LNG. In fact, it must be compared with the large-scale transport activities of LNG that involves regasification in the terminals connected with the natural gas transport networks. In this context, SSLNG-related services include different segments of a supply chain that involves various subjects / operators.
With reference to Figure 3.3, "Small Scale LNG" type services, already in place or under study, can be provided through the following infrastructures (or installations) [3.7]:

- Regasification terminals, which offer LNG loading services on bunker ships (lighters), tankers or tank wagons, as well as gas vaporization;
- Bunker ships (shuttles / shuttles), which in turn supply LNG-powered ships (bunkering) or local coastal storage;
- Mini liquefaction plants for the transformation into LNG of natural gas coming from the network, used to supply tankers and / or barges / shuttle ships for coastal plants;
- Autobotti (or ISO-container), which in turn supply LNG-powered ships (bunkering) or local storage;
- Local storage, supplied by tankers or barges for stock removal services.

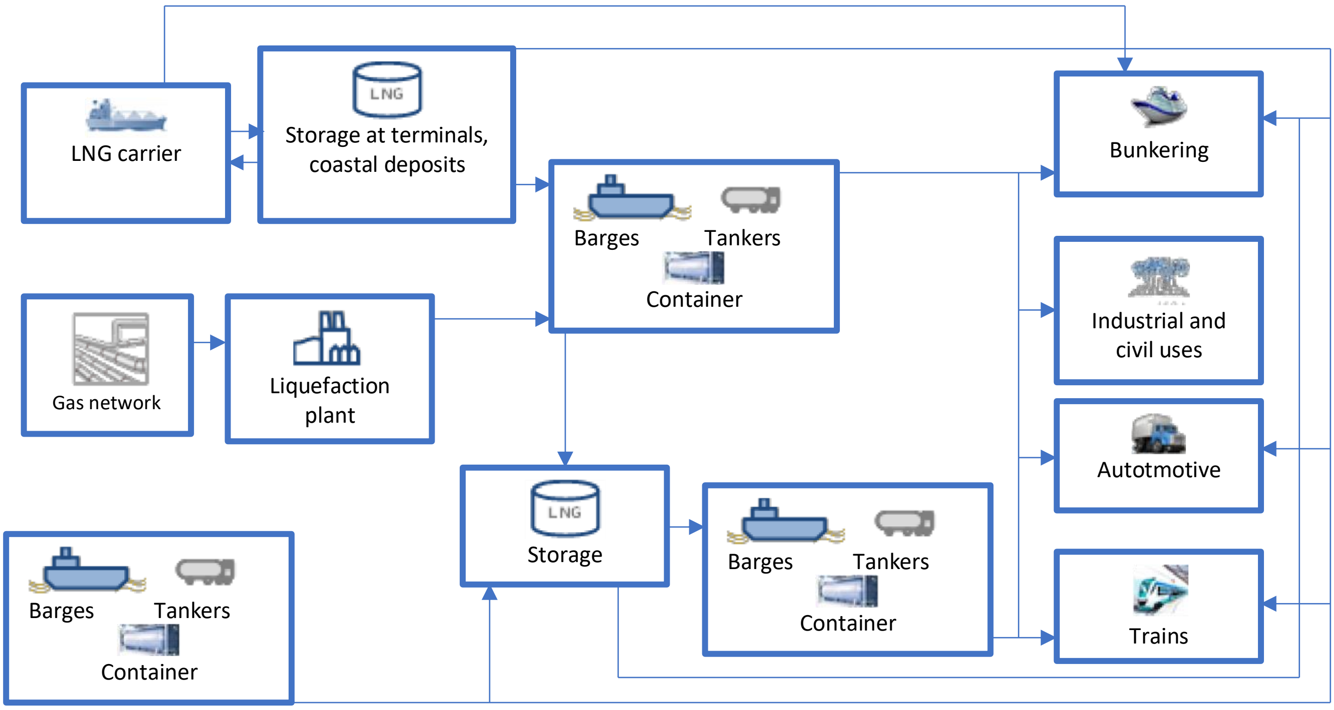

Figure 3.1 *SSLNG distribution methods scheme*

3.3.1.1 Import Via Truck and Trains

The activities and infrastructures needed to reach end customers are a network that allows the connection between LNG storage points and loading terminals. Different types of transport can be used, such as tankers, small and medium-sized ships, wagons equipped with cryogenic tanks or ISO containers. The final storage points are equipped with a gasification and compression plant that allows the use of natural gas in the usual way for the supply of single production units, isolated local distribution networks or refueling stations for motor vehicles powered by compressed natural gas. Storage facilities for end uses directly supply LNG transport vehicles equipped with cryogenic tanks that allow the feeding of natural gas engines, whose technology was already well known because they were used from the beginning in the large tankers and from the Fifties in the Automobiles. This allowed the use of natural gas as fuel for goods transport over long distances: heavy land vehicles and ships powered by LNG.
To date the only way to serve the demand is to import LNG from the terminals in Barcelona, Rotterdam and Fos-sur-mer (Marseille). In this case, a LNG vessel loaded with gas already liquefied at the point of production supplies a storage point in one of the terminals mentioned above. The terminal is a refueling point for tankers, trains, and barges, which carry supplies to Europe. Consequently, Italina companies depend on the large LNG terminals throughout Europe[4], forced to charge an excessive transport cost on the price for the end user: transport must travel very long distances to reach the final customer. The

[4] Just think about the impact that strikes and pollution have on heavy transport: from the revolt of the "Yellow Vests" in France or the bans on the circulation of diesel trucks on the Brenner highways

infrastructure network for the widespread use of small-scale LNG (SSLNG) is already present in some European countries, in particular Spain, Great Britain, Holland, Belgium, France and Portugal, equipped with regasifiers whose deposits have been adapted for the collection of LNG for the refueling of tankers and more recently also for tankers for its transport .
This method to serve the LNG demand is the one currently used, but will have a short life [3.8]. In fact, the chain that has been established in these years is particularly long. Countries like Italy that do not have large natural gas fields or biomethane production plants, nor terminals from which to take LNG, pay dearly for the different steps of logistics, which as already mentioned above has a heavy impact on the price the final. But this is just one of the problems that result from the complexity of this chain: just think of the rigidity of the logistics. In fact, the final distributors in Italy are unable to cope with possible fluctuations in demand, which is critical knowing that it is rapidly increasing. Any obstacle of a political or social nature can have an impact on the distribution, generating the possibility of leaving the distribution plants without an evident loss of revenues. This argument is also closely connected to the dependence that Italian distributors have on European terminals.
As can be seen from Figure 3.4, LNG refueling infrastructures for transport are lacking in central and southern Italy. This is another of the effects of the current supply logistics. In fact, suppliers in the south are always obliged by one of three European terminals, but the greater the distance from the supplier, the greater the transport cost to be applied to the final price. As a result, all LNG trucks heading south in Italy with an autonomy of around 1600 km, have the possibility to refuel in central Italy, perform deliveries in the south and go back without having to refill the tank again.
In the case of the import of LNG, since the gas is extracted and liquefied in the country of origin, it is not possible to produce bio-LNG.

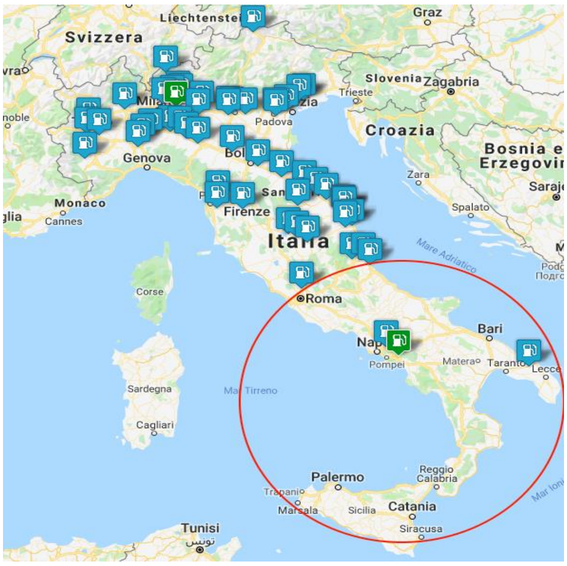

Figure 3.2 Distribution of LNG service stations [3.9]

3.3.1.2 Micro-Liquefaction

In this case, the gas pipelines on Italian soil are used. A percentage of gas is then taken and made liquid in order to store it. The micro-liquefactors would have a maximum storage of

500 m3, a quantity that would allow supporting the demand for LNG for transport. Moreover, this type of storage would allow to manage the oscillations of the demand: being the liquefier directly connected to the gas network, the manager can decide the amount of gas to be liquefied.
This alternative logistics would make it possible to serve the distributors located in geographical areas without a network, allowing the tankers to load LNG which will supply the distributors. Despite this, the micro-liquefier can be positioned near a consumption center, limiting secondary transport.
This alternative is the only one that supports the production of bio-LNG. In fact, the biomethane introduced into the network from the production sites would not only reach the stove and boilers for heating, but also the liquefier.
In this case the price of LNG at the pump would depend strictly on the imported natural gas.
With reference to Figure 3.5, liquefaction leads to an integrated business model that sees two different ways of producing gas: on the one hand the biomethane discussed in Chapter 2, on the other the gas network managed by SNAM.

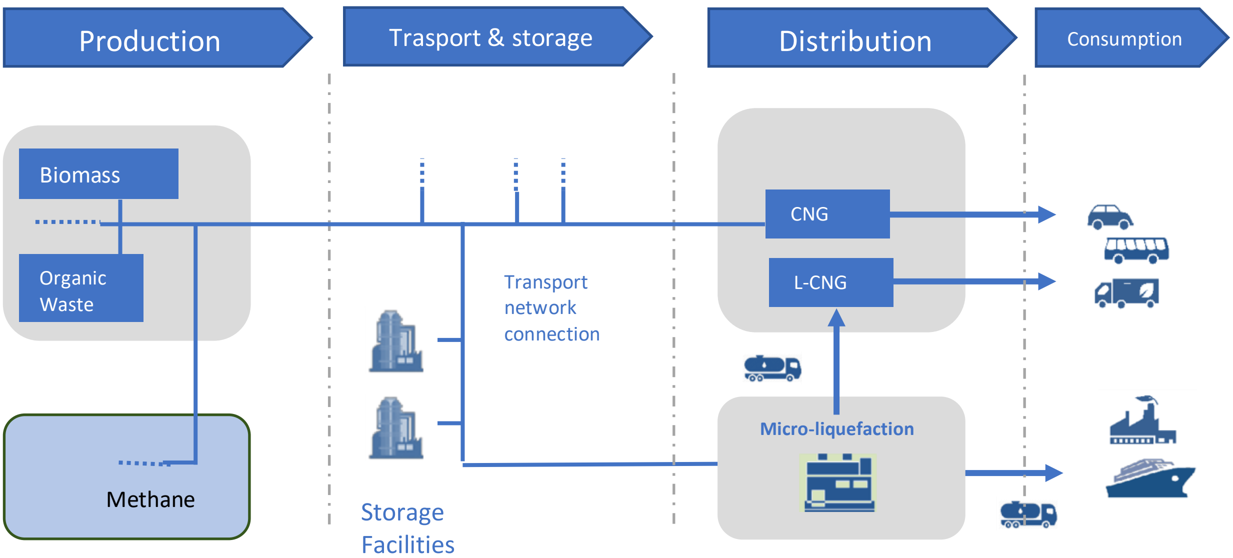

Figure 3.3 *Connection of the gas network with liquefers and service stations [3.10]*

The objective of this logistics is to transport the gas from the production points directly to the sales points. In this way, if it is a CNG that feeds cars, it is possible to reduce the size of the supply chain by avoiding distribution through trucks from the point of production to the filling station. The station can in fact be connected directly to the network. Instead, the CNG entered on the network can be taken to the point of sale following a longer tour, but useful if you intend to sell LNG. In fact, the liquefied gas can undergo two different destinies in the station: the first is to be sold as it is as a motor fuel, the second to be re-gasified and sold as CNG. The liquefaction alternative has an advantage in economic terms because, as already explained in the introduction, the liquid gas reduces its volume by 600 times.

3.3.1.3 Coastal Deposits

Coastal deposits, unlike micro-liquefators, have a high storage capacity (greater than 9000 m3), with the aim of satisfying demand not only for road transport but also for maritime transport.
Deposits are supplied directly by methane tankers that come from the production points loaded with LNG already liquefied on site. In fact, deposits are often placed near regasifiers, which are in turn supplied by methane tankers.
The initial investment is orders of magnitude higher than the previous solution, justified by the higher storage capacity and the size of the infrastructure.
Large warehouses require not only a larger investment, but also numerous operators and infrastructures to lean on[5]. In fact, they are involved [3.11]:

- LNG terminals, which can be either offshore or onshore;
- Bunker ships, ships that carry gas to the terminal;
- Secondary transport by tanker, for distribution logistics and bulk-breaking;
- Final customers, made up of wholesale distribution companies, and ships for maritime transport.

The price to the final consumer in this case depends on the world LNG market, due to the fact that the companies that sell crude also produce gas. Despite this, this relationship is diminishing, also thanks to American shale gas, announcing a new marriage between gas and the price of coal [3.12].

3.4 Illustration of a Gnl Service Station

The liquefied gas is then taken from the production points, to then be transported to the points of sale scattered in the geographical region. Each service station has a small storage center, corresponding to a cryogenic tank that keeps the liquid at the correct temperature to avoid the risk of boil-off.
The tanker then pours the LNG into the tank, which can be supplied for refueling. In the case of LNG refueling, the fuel is fed directly from the tank to the tank of the truck via a pump. Instead, in the case of CNG refueling, the liquid gas must be converted. The supply line is therefore slightly more complex because the LNG must first be vaporized. Then the steam is stored in storage cylinders before being dispensed by the pump.

[5] In the case of Ravenna, where a regasification plant is planned, Edison and PIR (Petrolifera Italo Rumena) have created the newco Depositi Italiani GNL to build a coastal depot. Edison deals with the construction of the depot and the refueling of the same by means of methane tankers and Knutsen of the construction of the ships. PIR, on the other hand, is the concessionaire of the port wharf air and guarantees the surface right of the area.

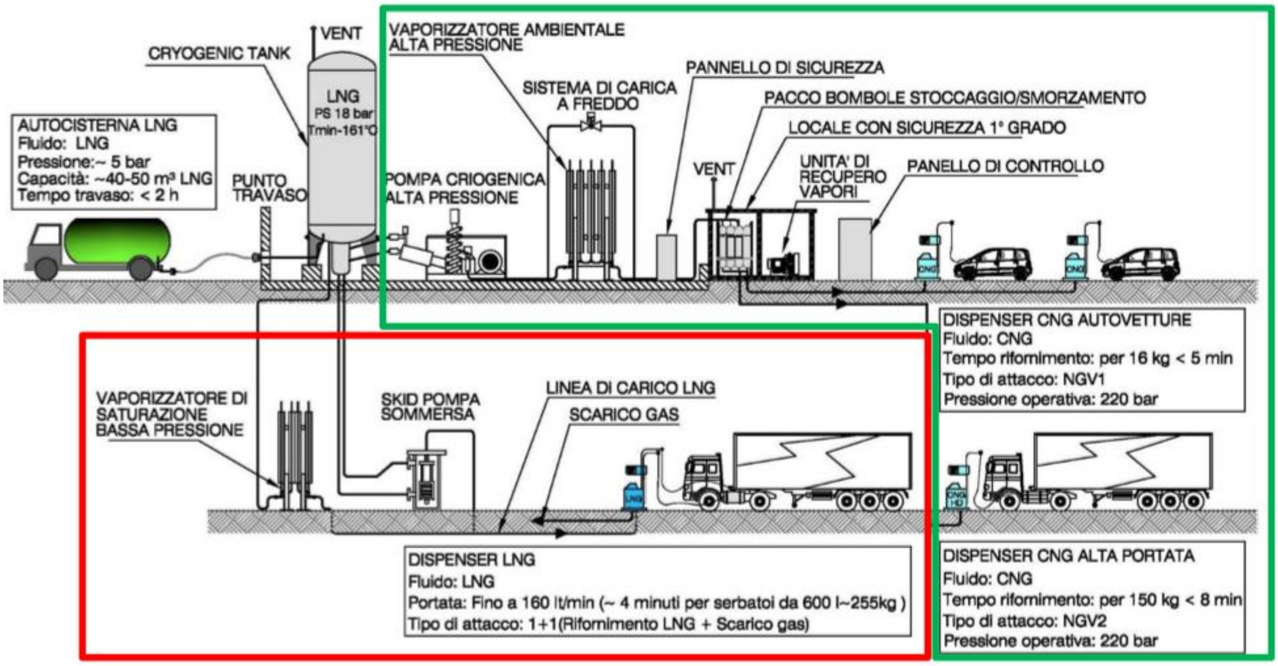

Figure 3.4 LNG service station operation illustration [3.13]

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Chapter 4

Entering LNG and bio-LNG in the Fuel Network Market

LNG and bio-LNG for transport have the same uses but different origins. Therefore it is necessary to carry out a different analysis for both products. LNG is imported from countries with large deposits (Qatar, Algeria) and its market is characterized by a particularly long supply chain. In fact, the LNG that arrives in Italy through importation, is first of all extracted from the field in the point of origin, liquefied on the spot, introduced itself in a methane tanker that covers many miles before arriving in Italy. The ship, once at its destination, places the LNG in a warehouse. From here it is picked up and transported to countries that, like Italy, do not have a terminal or a depot. The opposite for bio-LNG, whose production points scattered throughout Italy contribute to the disposal of FORSU, by injecting biomethane directly into the network which is then liquefied elsewhere.

Worldwide, almost 30% of natural gas is transported in liquid form, exploiting the property inherent in the liquefaction of natural gas. A methane carrier carries an average of 130,000 cubic meters of liquefied methane, which corresponds to 78 million cubic meters in the gaseous state, although the trend is for ever larger methane tankers [4.1].

The first part of the chapter therefore deals with the introduction of LNG in the network by analyzing the position of the producers, market trends and the objectives that will be achieved to enter the LNG on the network to remedy the problems reported in the previous chapter and above. In this regard, the network is analyzed starting from production points.

The second part deals with the introduction of biomethane into the network, which occurs through the use of consumer certificates (CIC), which also make it possible to carry out an economic return analysis in terms of incentives.

4.1 Advantageous Position of the Producers

Multiple reasons (technological, political, economic, environmental) have contributed over time to the development of LNG which now competes with pipeline transport over medium distances. Its most obvious advantage is the possibility of reducing the importance of the geographical variable in the international gas trade, obviating the rigidity which the use of gas pipelines that unequivocally link the source of consumption with the point of consumption requires. Long distance sea transport (similar to that of oil) has contributed to the emancipation of gas from purely regional borders, allowing a gradual globalization of the market with a strong acceleration in the last decade.

This has benefited primarily consumers and producers who have an unfavorable geographical position and do not have significant own resources. On the other hand, Qatar is the world's largest producer [4.2], a country that is relatively poor in oil but rich in gas, far from the major consumer basins. Qatar's exports therefore turned towards Europe and towards Asia Pacific. However, those countries that have aimed to increase their energy security by expanding and diversifying their import sources have also benefited from the development of LNG. For this aspect, the most interesting example is Spain, which by introducing a limit to pipeline imports in the 1990s has favored the development of regasification plants, a sector that today sees it as a European leader.

More generally, many European countries, despite their geographical proximity to important export areas - such as Russia and North Africa (Algeria and Libya) - have gradually resorted to LNG as the entry of new producers has fostered a more open market. competitive.

4.2 European Strategy

On 22 October 2014, the European Union adopted Directive 2014/94 / EU for the dissemination of alternative fuels and the construction of related infrastructures uniformly throughout the Union along the main corridors and infrastructural routes, both for maritime and land transport.In abbreviation, the directive has been called DAFI (Directive Alternative Fuel Infrastructure). The measure supports the increase in the use of electricity, hydrogen and natural gas (compressed and liquid) in transport in order to reduce the consumption of petroleum products and consequently pollutant emissions, and to improve the quality of the air is for the reduction of climate-changing emissions.The main requirement set by the LNG sector directive, to be implemented by November 18, 2016, was the adoption by each member country of a national strategic framework with the goal for the maritime sector of the development of a European network refueling points for ships that include terminals, storage facilities, port facilities equipped for tankers, tankers for transport and bunkering and for the heavy land transport sector the objective of ensuring an adequate distribution system among the intermediate deposits and filling stations for the trucks. Directive 2014/94 / EU explicitly identifies LNG as an alternative fuel to allow ships to meet the requirements for reducing sulfur content in marine fuels, as required by Directive 2012/33 / EU, and for trucks to comply with the emission limits set by the Euro VI standards, pursuant to regulation (EC) no. 595/2009.National strategic frameworks must include:

- an assessment of the current status and future developments of LNG as an alternative fuel;
- national objectives for infrastructure construction;
- the measures necessary to achieve national objectives.

In particular, the directive has provided that in each member country an adequate number of LNG refueling points in sea ports will be implemented to allow navigation of LNG-powered ships in the TEN-T core network (Trans European Networks - Transport) and likewise for public road refueling points always along the central TEN-T road network for heavy vehicles. For the supply of refueling points, an adequate LNG distribution system must be guaranteed, which in a first phase can exploit the primary deposits annexed to the large regasification plants present in almost all European countries.

4.3 Italian Objectives

The Strategic Framework formulated 2030 as the main deadline for developing hypotheses, when it is desirable to build an infrastructure for the reception and use of LNG on the national territory, with the installation of equipment sufficient to cover a global market volume of 3, 2 million tons of LNG, corresponding to 4 million TOE (tons of oil equivalent).
To achieve this objective, the Strategic Framework assumes the realization of:

- 5 LNG coastal deposits of 30,000/50,000 m^3;
- 3 cabotage ships of 25,000/30,000 m^3;
- 4 LNG supply lorries to ships;
- about 800 LNG service stations, also equipped with L-CNG dispensers.

Furthermore, as specified in the previous chapter, the DAFI envisaged the construction, by December 31, 2025, of an adequate number of LNG refueling points accessible to the public at least along the TEN-T core network. To define the number of refueling points on the road, the directive suggests taking into account the minimum autonomy of LNG-powered heavy vehicles, indicating, by way of example, an average distance of 400 km.
The TEN-T network covers the entire national territory with a higher concentration in the north of the country; in particular it has about 3,300 km of total road, divided into 3 main corridors:

- Palermo-Naples-Rome-Bologna-Modena-Milan-Verona-Brennero;
- Genoa-Milan-Chiasso e Genoa Voltri-Alessandria-Gravellona Toce;
- Frejus-Turin-Milan-Bergamo-Verona-Padua-Venice-Trieste.

Figure 4.1 TEN-T network in Italy

From an economic analysis point of view, the government document provided that the positions that intercept already consolidated traffic flows for the heavy transport of goods would be privileged. In fact, the profitability of the plants appeared to be very low due to the absence on the national territory of a supply base (primary storage) for cryogenic tankers and that this "would have represented an important brake to the development of the road distribution network". The effectiveness of using LNG to reduce the emission of greenhouse gases into the atmosphere depends on the type of engine and the range of possible measures that can be taken to reduce the unwanted release of natural gas, being itself a greenhouse gas. Since it is likely that each regasification, reception or secondary storage terminal will have a loading point for LNG tankers, except for offshore plants, such as the two located offshore of Livorno and Rovigo, the hypothesis of the strategic framework regarding primary and secondary storage facilities that will be able to supply the tanker trucks is 5 to 2020, 7 to 19 to 2025 and 10 to 35 to 2030.
On the basis of a questionnaire filled out by companies interested in the design-construction of plants in the energy supply chain, the Strategic Framework has also formulated cost hypotheses (limited only to technological works and professional charges) for the construction of small storage sites (deposits satellite) for systems serving civil users (small ducted networks) and commercial/industrial plants.
For these plants the cost net of VAT assessed in 2016 for tanks with a capacity of between 30 and 50 tons varies from € 270,000 to € 350,000. At this price must be added other components such as vaporizers, regulators, connections in cryogenic ducts, as well as costs for building works, for safety measures and/or for fire protection systems [4.3].

4.3.1 GNL Demand Forecasting

The LNG demand forecast in Table 4.1 [4.3] for heavy land transport was calculated in relation to the number of vehicles expected depending on the oil price trend, in a range between 30 and 100 $ / barrel. The off-grid market considered includes both industrial consumption and those relating to means of transport and civil uses.
As regards storage points, on the other hand, the minimum requirement set by the EU in terms of distance between LNG depots is 400 km. This could be satisfied in Italy with 5 well-placed deposits.

Table 4.1 Forecast for quantities of LNG fed into the network, storage facilities and deposits

Application	2020 Forecasting	2025 Forecasting	2030 Forecasting	Note
Lumping (primary) LNG plants at regasification terminals and / or receiving terminals	3	4	5	Deposits from 30,000 to 50,000 m^3
LNG storage facilities (secondary)	5	15	30	For a size of 1500 cubic meters liquid up to 10,000 cubic meters liquid
CNG refueling facilities integrated with LNG	2%	10%	800	
LNG heavy transport vehicles new vehicles	-	-	2-15% 30.000/35.000 vehicles	Percentage on the non-fuel and dual-fuel vehicle fleet
Application for LNG for heavy transport (ton / year)	400.000	1.250.000	2.500.000	
LNG demand for light transport L-CNG (ton / year) MIN	-	-	500.000	
LNG demand for light transport L-CNG (ton / year) MAX	-	-	1.000.000	
LNG application in the OFF-GRID market (ton / year)	-	-	Industry: 1.000.000-2.000.000 Civil: 300.000-600.000	
GNL question bunker (ton)	-	800.000	1.000.000	
New construction LNG powered vessels	2	20	35	
Conversion of vessels powered by LNG	5	20	25	
Loading points for LNG tankers	5	7	10	
Number of LNG refueling points accessible to the public along the TEN-T network	3	5	7	
LNG refueling points for ships operating in seaports and inland ports	10	13	20	

By 2020, assuming 3 coastal depots and 5 secondary storage facilities, of which half are hypothetically internal, we will reach about 5 coastal refueling points. Adding ports served

by barges and any refueling points along inland waterways can be as high as 10. Taking into account that the main ports are 14 and that some other ports may be interested in the opportunity by size or type of traffic, 12 ports can be assumed at 2025 and 20 at 2030.
The expansion of the number of service stations that supply methane (L-CNG) in densely urbanized areas (eg Rome, Milan, Naples, Turin) thanks to the availability of LNG, could favor the diffusion of cars with this power supply, together with the confirmation of incentives already provided for at national and regional level.
It is estimated that at least 10% of the new CNG service stations that will be built in the next few years in urban and extra-urban areas could be powered by cryogenic tankers rather than methane pipelines, in order to allow the delivery of LNG in the liquid and / or gaseous state.
The development of activities in the energy sector represents a potential driving force of economic recovery that can move huge investments and allow to build future savings as well as being, in general, a bearer of innovation and induced. In the time horizon to 2030, the prospects for penetration of 20% of LNG in the market just described represent a realistic goal, the achievement of which must be supported by concrete solutions for the emergence of logistic infrastructures capable of responding effectively and economically to sustainability. energy demands of the sector.
From the distribution of consumption it appears evident the need to prepare, also for off-grid uses of LNG, a distribution structure that ensures a homogeneous availability of the product in our territory with storage infrastructures capable of satisfying a request that can be quantified, for the several off-grid applications, in around 3.5 million cubic meters of LNG.
The forecasts of LNG penetration in the mature market of utilities not connected to the natural gas distribution network in Italy set as a goal of long-term consumption, ie 2030, about 1 million tons of LNG consumed by industrial users, from 0 , 5 to 1 million tons consumed by users of the distribution of L-CNG for automotive use, and about 0.3 million tons consumed by off-grid civil users.
The possible total consumption for users not connected to the natural gas distribution network is between 1.8 and 2.3 million tons of LNG. The distribution of current consumption means that, for industrial consumption, greater demand is expected from the regions of the north-west and the south, in particular the two largest islands.
However, these prospects could be modified if, in the wake of the Community policies aimed at reducing air pollution, policies were implemented to improve air quality parameters that saw the natural characteristics of LNG as an important tool to push down the reduction of major air pollutants. For the consumption of L-CNG they could be distributed fairly evenly throughout the country if the distribution infrastructures reach an adequate capillarity on the motorway network and in the major population centers.

4.4 Entering the Biomethane Network

In December 2008 the "Climate and Energy Package" was approved, aimed at completing the objectives of the 20-20-20 strategy. In particular, it contained the Renewable Energy Sources Directive (Directive 2009/28 / EC) which was implemented with the legislative decree of 3 March 2011, n.28. A series of ministerial decrees have been issued to define the tools, mechanisms, incentives and institutional, financial and legal framework

necessary to achieve the targets set for 2020 for the overall share of energy from renewable sources.
However, given the small number of plants built for the production of biomethane made from 2013 to today [4.4], for this reason the Ministry of Economic Development issued a new ministerial decree on March 2, 2018, in which it promotes exclusively:

- Biomethane introduced into the natural gas network without a specific use destination by issuing guarantees of origin;
- Biomethane introduced into the natural gas network with a specific destination in transport;
- Advanced biomethane introduced into the natural gas network and intended for transport;
- Advanced biofuels other than biomethane released for consumption in the transport sector;
- The conversion of existing biogas plants.

The Energy Services Manager therefore regulates the operating procedures for the issue of the qualification and for the determination and recognition of the incentives.
In particular, as envisaged by the so-called "Iluc" directive, the aim is to reach the 10% target of renewable energy consumption in the transport sector by 2020 and the specific result of 0.9% for advanced biofuels on the same date , which becomes 1.5% by 2022. The target for advanced biofuels must be met by 75% biomethane and 25% by biofuels of other species. Thanks to these decrees, Italy will adopt the instrument of the "Consumption Entering Certificate" (CIC), the carrier of a mandatory biofuel entry system for transport.

4.4.1 Incentives for Biomethane

For plants destined for the production of advanced biomethane, the decree provides for a maximum incentivable annual production of 220.913.107.5 standard cubic meters.
Article 5 of the Decree encourages the production of biomethane for the introduction into the natural gas network with a specific destination for transport through the issue of Certificates of Consumption Release (CIC). CICs are issued monthly: even advanced biomethane producers may require the application of the conditions to the art. 5 of the decree, obtaining the release of advanced CICs which however are outside the increases due for liquefaction and distribution. A CIC attests the entry of:

- 10 Gcal of biofuel, including biomethane;
- 5 Gcal of advanced biofuel, including advanced biomethane, or non-advanced biofuel but produced from the raw materials listed in Annex 1 Part 2-bis of Legislative Decree 3 March 2011, nr. 28.

Furthermore, CICs are differentiated by type in:

- "CIC", issued for the release for consumption of biofuels, including biomethane, produced from raw materials not listed in part A of Annex 1, part 2-bis of the decree of 3 March 2011;
- "Advanced biomethane CIC", issued for the release into consumption of biomethane produced from the aforementioned raw materials;
- "CIC other advanced biofuels" issued for the release for consumption of other biofuels, but also produced from the aforementioned raw materials.

The incentives for the advanced biomethane producers envisaged by article 6 of the decree are:

- The withdrawal by the GSE of the biomethane that is introduced into the networks with the obligation of connecting third parties. The GSE recognizes to the producer a value equal to the average price weighted with the quantities, registered in the month of sale on the spot gas market (MPGAS) reduced by 5%. This percentage can be modified to meet the costs of transport from the biomethane collection point to the virtual exchange point (PSV).
- The GSE recognizes to the producer the value of the corresponding CICs and any increases, each certificate is given a value of 375 euros. This value remains unchanged throughout the incentive period, once the plant has entered into operation.

The producer can also request the partial withdrawal of the biomethane and arrange for the sale of the remaining part independently.
The incentive is scheduled for a maximum of ten continuous years. At the end of the ten years the Producer accesses the release of the CICs referred to in Article 5 of the aforementioned decree.
For the management of the incentive, the GSE publishes each year the estimates of the maximum annual amount that can be withdrawn and the value of the maximum annual amount that can be withdrawn for the previous year. Therefore the GSE publishes monthly:

- A ranking of the qualified plants in operation that require the withdrawal of the CIC;
- A biomethane and CIC collection counter for the annual quantity, annual quantity determined based on the producibility and the actual production of the plants in the ranking.

The maximum number of CICs due to each installation is determined based on the qualified production capacity of the GSE. The production plant operated by CTIP BLU srl, referred to in chapter 2, operates for a number of hours equal to 8300 (100% of operations).
The estimated annual producibility in CIC is determined by multiplying the production capacity of the plant in Sm3 / h qualified by the GSE, for the maximum number of operating hours per year (8300) for an estimate of the lower calorific value equal to 0.008111 $Gcal/Sm^3$ [4.5]. The value obtained is then transformed into CIC.
In the case in point for the plant subject of the following study we obtain [4.6]:

$$\text{Plant nominal productivity} = 354\ \frac{\text{Sm}^3}{\text{h}} \qquad (1)$$

$$\text{Number of CIC per annum} = \frac{354\ \frac{\text{Sm}^3}{\text{h}} * 8300\ \frac{\text{ore}}{\text{anno}} * 0.008111\ \frac{\text{Gcal}}{\text{Sm}^3}}{5\ \frac{\text{Gcal}}{\text{CIC}}} = 4766\ \text{CIC} \qquad (2)$$

For a total monetary value of € 1,787,380/year. If instead the maximum productivity of the plant is considered, 5197 CIC are obtained, for a total value of 1.948.875 €/year.

4.4.2 Plant Configurations

The 2 March 2018 Ministerial Decree provides for different incentives depending on the method of entering the network or the plant configuration. Also in this case, as reported in the previous paragraph, the incentive is determined by converting the quantity of biomethane introduced into the network (Sm^3) into a quantity of heat (Gcal). The application procedures provided by the GSE regarding the above DM, therefore show all the possible configurations that can be realized for the production of biomethane. Consequently, the generic configuration is represented by a production plant, a distribution system that connects the plant to the network or to the service station (liquefier, gas network etc) and the service station itself.
The producer who decides to invest in any of these three elements has the right to receive CIC as an incentive. Despite this, both the eventual distribution and the service station must be attributable to a specific production plant.

4.4.2.1 Determination of Incentives in the Configuration of Interest

The configurations reported in the application procedures drawn up by the GSE will be analyzed in order to get closer to the plant object of this report.
The first configuration involves the liquefaction of the biomethane at the exit of the upgrading unit, which is then transported in liquid form to the relevant distributor.

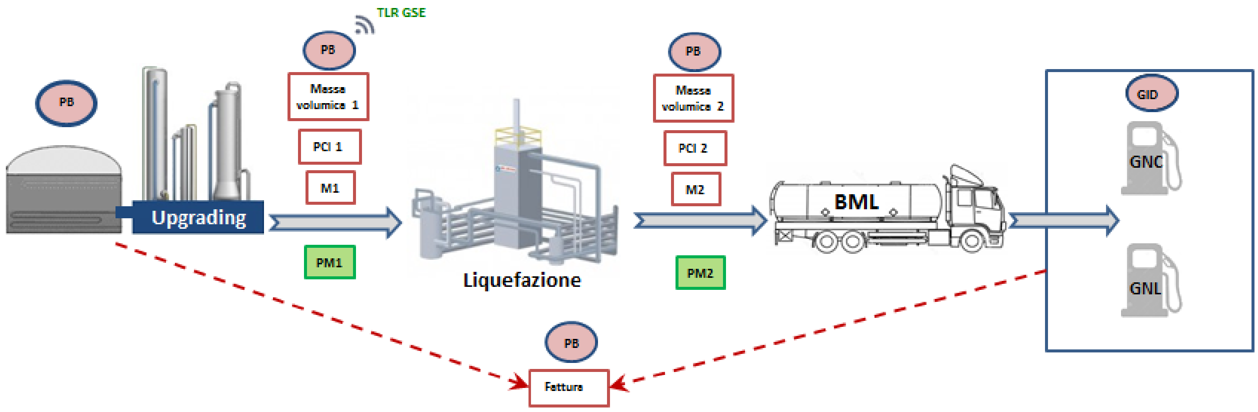

Figure 4.2 Configuration with production plant, liquefier and distributor relevant to the plant

The quantity admitted to the incentive is determined according to:

$$\mathrm{Ei_n} = \min\left(\mathrm{M1_n} \cdot \mathrm{LCV_n};\ \mathrm{Bill_n} \cdot \mathrm{LCV_{BML}}\right) \qquad (3)$$

Where:

- Ei_n is the incentivable energy of the n-th month;
- $M1_n$ is the monthly quantity of biomethane measured upstream of the liquefaction system;
- Bill_n is the monthly quantity of biomethane, as per invoices, sold by the producer to the distribution subjects;
- LCV_n is the average monthly lower calorific value, weighted according to quantities, and determined on the basis of the chemical composition recorded daily downstream of the upgrading;
- LCV_{BML} is the lower calorific value of the liquid biomethane conventionally assumed equal to 13.889 kWh / kg (50 MJ/kg).

In the second configuration instead, the manufacturer puts the biomethane directly into the network:

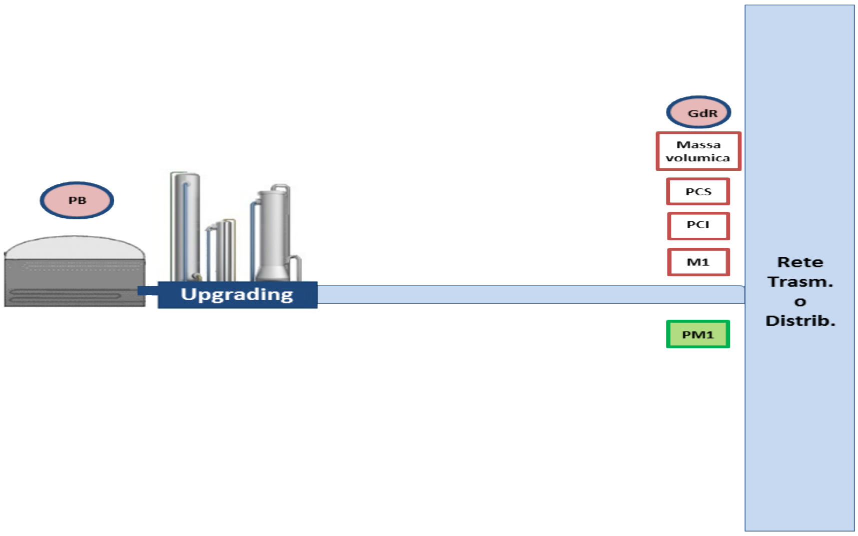

Figura 4.3 Configurazione con immissione di biometano direttamente in rete

The quantity admitted to the incentive is determined according to

$$\mathrm{Ei}_n = \mathrm{M1}_n \cdot \mathrm{LCV}_n \quad (4)$$

Furthermore, the amount of biomethane subject to collection is calculated:

$$\mathrm{EiRIB}_n = \mathrm{M1}_n \cdot \mathrm{SCV}_n \quad (5)$$

Where:

- $EiRIB_n$ is the energy withdrawn from the GSE in the nth month;
- SCV_n is the average monthly calorific value, weighted according to quantities, and measured at the point of entry into the network with third-party connection obligation.

4.4.3 Increase for the Construction of Relevant Distribution Plants

The decision to build a distribution system for the sale of biomethane, allowing the supply of a relevant producer, can allow an increase of:

$$\mathrm{M\ CIC\ distr}_n = 0.2 \cdot \frac{\mathrm{Bill}_n^p \cdot \mathrm{LCV}_n}{5} \quad (6)$$

Where:

- $\mathbf{M\ CIC\ distr_n}$ is the number of CICs due in relation to the increases for the construction of the relevant distribution system;

- $\mathbf{Bill_n^p}$ is the monthly amount of advanced biomethane, found from the relative billing, actually sold between the biomethane producer and the subject / owner of the relevant distribution plant;
- $\boldsymbol{LCV_n}$ average monthly value, weighted according to quantities, of the lower calorific value.

The increase in terms of CIC is granted up to the maximum until a cumulative number of CICs is reached equal to:

$$\frac{min\ (600.000; Total\ Investment \cdot 70\%)}{375} \cdot \%investment \tag{7}$$

dove:

- $\boldsymbol{Total\ Investment}$ is the total investment incurred by all investors, including the Producers, for the construction of the relevant distribution system;
- $\%\boldsymbol{investiment}$ is the percentage of participation in the investment for the realization of the relevant distribution plant by the specific Producer compared to the total invested by the Producers only. Therefore, this percentage is equal to 100% if there is only one advanced biomethane producer among the investors, who has invested at least 51% of the total investment.

4.4.4 Increase for the Construction of Relevant Liquefaction Plants

In the case of relevant liquefaction plants, it's allowed an increase in CIC equal to:

$$M\ CIC\ liq_n = 0.2 \cdot \frac{Ei_n^p}{5} \tag{8}$$

Where:

- $M\ CIC\ liq_n$ is the CIC surcharge due for the construction of the relevant liquefaction plant;
- $\boldsymbol{Ei_n^p}$ is the incentivable energy in the nth month, expressed in Gcal and determined according to Equation 3;

The increase in CIC is granted until:

$$\frac{min\ (1.200.000; Total\ Investment \cdot 70\%)}{375} \cdot \%investment \tag{9}$$

Where:

- $\%\boldsymbol{investiment}$ refers to the percentage of the same used to build the liquefaction plant.

These surcharges are for a maximum of ten years and are therefore issued by increasing the incentives by 20%, up to the achievement of 70% of the realization cost value up to the maximum limit of 1,200,000 euros. To certify the cost of implementation, an audit firm must draw up a report in which the invoices relating to the expenses incurred must be attached.

4.4.5 Case Study

To obtain the total number of CICs deriving from the supply chain in Figure 4.2, the contributions deriving from all the formulas shown up to now are added, obtaining:

$$CIC_{Advanced\ Biomethane} = \frac{Ei_n}{5} + \sum_{p=1}^{L} M\ CIC\ liq_n^p + \sum_{p=1}^{P} M\ CIC\ distr_n^p$$

$$= \frac{Ei_n}{5} + 0.2 \cdot \frac{Ei_n}{5} + 0.2 \cdot \frac{Bill_n^p \cdot LCV_n}{5} \qquad (10)$$

Where:

- $CIC_{\text{Advanced Biomethane}}$ is the number of advanced CICs due in the nth month to the producer;
- Ei_n is the incentivable energy determined according to equation (3);
- $\boldsymbol{M\ CIC\ distr_n^p}$ is the CIC surcharge due in the nth month for the construction of the relevant distribution plant p;
- P total number of distribution plants built;
- $\boldsymbol{M\ CIC\ liq_n^p}$ is the CIC surcharge due in the nth month for the construction of the relevant liquefaction plant p;
- L is the total number of liquefaction plants relevant to the realized biomethane plant.

Applying (10) to the case study of chapter 2, which takes into account the Mosciano Sant'Angelo production plant. Furthermore, the presence of a liquefier and a relevant distribution system is considered.

$$Q = 354 \frac{Sm^3}{h} \qquad \text{Plant Productivity (11)}$$

$$M1_n = \frac{354\,\frac{Sm^3}{h} \cdot 8300\,\frac{h}{anno}}{12} = 244.850\,\frac{Sm^3}{mese}$$ Monthly Biomethane Production (12)

$$Ei_n = 244.850\,\frac{Sm^3}{mese} \cdot 0.008111\,\frac{Gcal}{Sm^3} = 1986\,\frac{Gcal}{mese}$$ Monthly Incentive Energy (13)

$$CIC_{Advanced\ Biomethane} = \frac{1986\,\frac{Gcal}{mese}}{5} + 0.2 \cdot \frac{1986\,\frac{Gcal}{mese}}{5} + 0.2 \cdot \frac{1986\,\frac{Gcal}{mese}}{5}$$ Montly CIC Number (14)

According to (14) the $CIC_{\text{Advanced Biomethane}}$ amount to 556, resulting in a total monthly incentive of 556 * 375 = € 208,530. The CIC contribution of the production plant is much higher than that of the liquefier and the station, determining 71% of the incentive. Furthermore, as can be seen from (7) and (9), the CICs for distributors and liquefactors are paid until their accumulated value reaches a percentage of the investment determined by the equations themselves. The situation changes considerably with regard to the producer, who instead has the right to receive CIC for 10 years from the start-up of the plant.
The value of the monthly CIC determined, corresponds exclusively to the incentive envisaged by the legislative decree of March 2, 2018. In fact, the revenues of a biomethane production plant also contain items relating to the biomethane sold, the compost and the payments made by the municipality for services offered relating to waste treatment.

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Chapter 5

Economic Evaluation of a Biomethane Liquefier

This chapter introduces a feasibility study relating to the investment of a liquefier. The latter is intended to liquefy the entire biomethane output produced by the plant, which will then be stored on site and then transported to service stations.
The cost of the liquefier was made through empirical estimates that price the component system by component. The sum of the prices obtained returns an order of magnitude of the cost of a liquefier, which however differs from a quote.
Once the value of the initial investment has been assessed, we move on to economic analysis. Several perspectives have been taken into consideration: in the first case the investment is made by Petrolbitumi srl (which deals with the distribution of LNG), in the second case by CTIP BLU srl (which deals with the production of biomethane). Then the situation is evaluated in which the producer decides not to invest in the liquefier, but to construct the infrastructure for placing the biomethane on the grid. The last part of the chapter aims to compare the situation in which the producer invests in liquefaction with that in which he introduces the gas into the network.
In addition to the feasibility study, we evaluate the convenience that a fuel distribution company has in terms of reducing transport costs. As explained in the previous chapters, to date the latter is excessively high due to the fact that the LNG must be imported from France.

5.1 Case Study Description

The analysis is based on the comparison of two different systems, which can be summarized in Figure 5.1. The first represents the liquefaction process by which the bio-LNG produced is stored in a tank at the end of the process. Then it is taken from a tanker and distributed. In the second case instead, biomethane is directly placed on the network.
For the study, a nominal inlet flow of biomethane of 355 Sm3 / h is assumed and in both cases the gas comes from an upgrading station. Not all processes in common with the two cases are considered, which would be redundant.

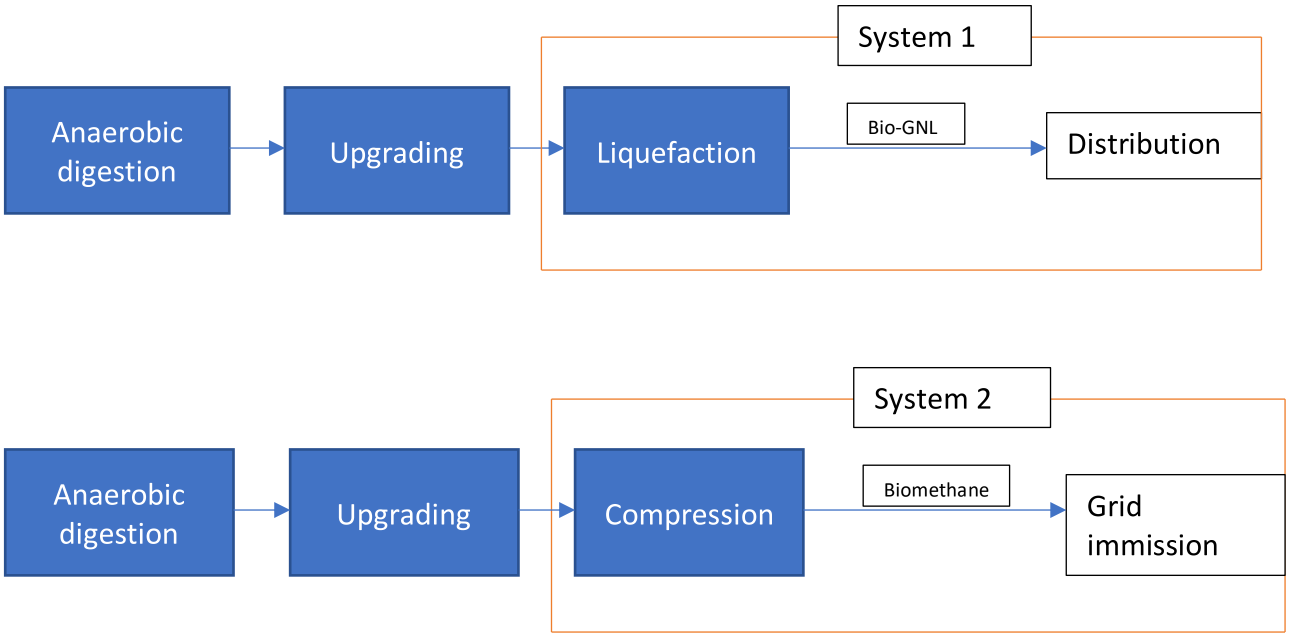

Figure 5.1 Scheme representing the two system analyzed

5.2 First System: Bio-LNG Production

The first system corresponds to a liquefier. It is possible to break down this system into two different lines, which exchange heat in a single point corresponding to a heat exchanger. The first line consists of a series of compressors and systems for cooling the gas exiting the compressors themselves. The cooling of the gas in this area is not sufficient to liquefy the biomethane, a process that takes place inside the heat exchanger. The gas that has now become liquid is kept inside a tank. Instead, the percentage that has remained in the gaseous state is taken and sent to the beginning of the biomethane line.
The second line cools the nitrogen through a Joule-Brayton cycle. Initially nitrogen is carried by a series of two compressors from an "average" to a "high" pressure, while the residual heat is removed by a cooling system. From here the nitrogen line splits: the first flow enters the heat exchanger and then into the high pressure expander. The temperature reached by the nitrogen in this flow has the purpose of pre-cooling the biomethane and regenerating the cycle. In fact, being passed back inside the heat exchanger is returned to the beginning of the cycle. The second flow is relative to the low pressure expander, where the nitrogen reaches the temperature of -160 ° C and is sent to the heat exchanger where the low

temperature is sufficient to liquefy the biomethane. From here the nitrogen, before restarting the cycle, undergoes a compression and a cooling.

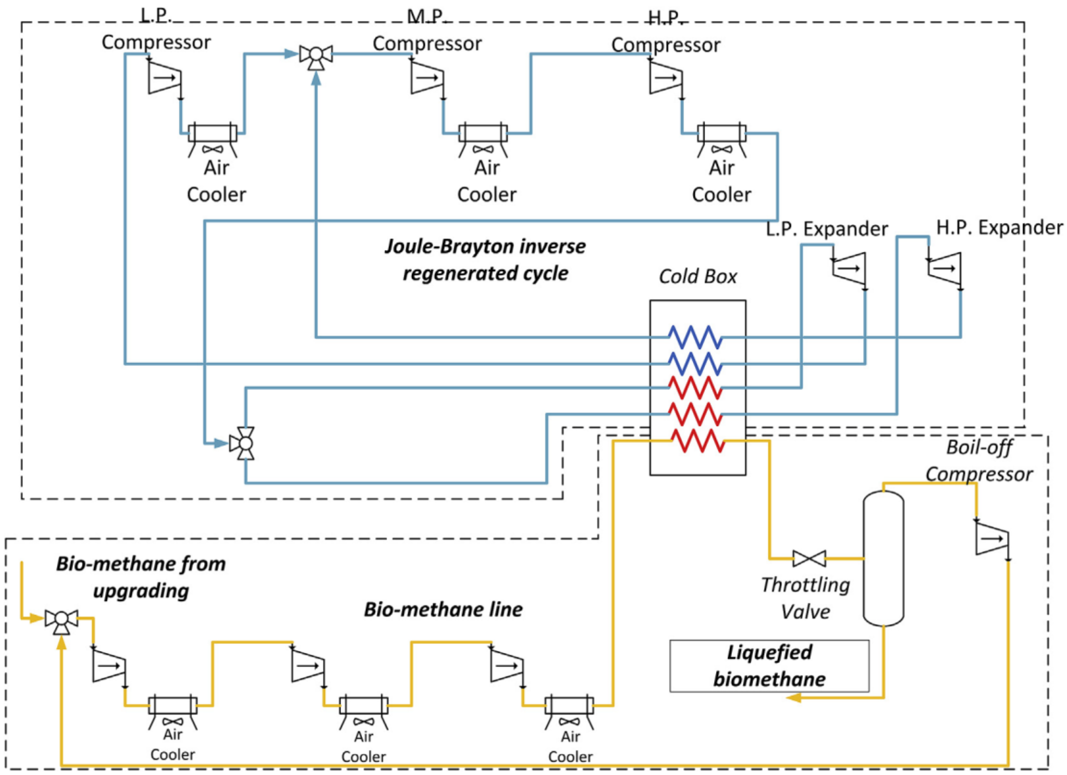

Figure 5.2 Liquefaction system

5.2.1 First System: Cost Analysis

The procedure provides an estimate of the costs of the various components of the liquefier. It is possible to determine the estimate of the purchase cost of the cooling systems, expanders, bio-LNG storage tank and separator of the liquid fraction from the gas fraction, through the following expression [5.1, 5.3]:

$$\log_{10} C_{p0} = K_1 + K_2 \log_{10} A + K_3 (\log_{10} A)^2 \tag{15}$$

Where:

- A, characteristic parameter of the system under consideration: the heat exchange surface for a cooling system, mechanical power (if considering a radial turbine as an expander), volume for tanks and separators;
- K_i, constant typical of the type of equipment;
- C_{p0}, purchasing cost.

To determine the final cost estimate, it is also necessary to estimate the characteristic components for each system. For the cooling system a heat transfer coefficient is determined [5.2], for the turbine the operating pressure [5.1]:

$$\log_{10} F_p = C_1 + C_2 \log_{10}(P_g \cdot 10) + C_3 (\log_{10} P_g)^2 [\log_{10}(P_g \cdot 10)]^2 \tag{16}$$

Where:

- F_p expresses the estimate of the working pressure;
- P_g the relative pressure;
- C_i represents constants that depend on the type of system.

As regards the estimate of F_p for the tank and the separator, it is possible to use [5.1]:

$$F_p = \frac{\frac{(P_g \cdot 10 + 1) \cdot D}{2 \cdot (850 - 0.6(P_g \cdot 10 + 1))} + 0.00315}{0.0063} \tag{17}$$

Once the value of F_p is estimated, it is possible to determine the value of the system that takes into account both direct and indirect costs: material and labor costs [5.1]:

$$\mathrm{C_{TBM}} = \mathrm{C_{p0}} \cdot (\mathrm{B_1} + \mathrm{B_2} \cdot \mathrm{F_m} \cdot \mathrm{F_p}) \tag{18}$$

Where:

- F_m takes into account the construction material;
- B_i are constants that depend on the system.

As far as compressors and expanders are concerned, it is possible to estimate the purchase cost starting from the power:

$$\mathrm{W_c} = \frac{\dot{\mathrm{m}} \cdot \Delta \mathrm{h_{is}}}{\eta_{\mathrm{is}}} \tag{19}$$

$$\mathrm{W_e} = \dot{\mathrm{m}} \cdot \Delta \mathrm{h_{is}} \cdot \eta_{\mathrm{is}} \tag{20}$$

Where:

- $\dot{\mathbf{m}}$, esprime la portata del gas in [kg/s]
- $\Delta \mathbf{h_{is}}$, the isentropic variation enthalphy
- $\boldsymbol{\eta_{is}}$, the isentropic efficiency

Once the respective powers have been obtained, the costs are calculated starting from a known compressor / expander [5.1]:

$$\left(\frac{\mathrm{C_a}}{\mathrm{C_b}}\right) = \left(\frac{\mathrm{A_a}}{\mathrm{A_b}}\right)^{\mathrm{n}} \tag{21}$$

Where:

- C_a, cost of the compressor / expander to be obtained;
- C_b, reference compressor / expander cost;
- A_a, attribute relating to the compressor / expander, in this case a power in kW;
- A_b, attribute relating to the reference compressor / expander, in kW;
- n, exponent usually established by the rule of six tenths, therefore equal to 0.6.

Despite this, since the compressors are machines whose data can easily be found online [5.4], a regression line was determined:

$$C_{p0} = 124.813 \cdot (\dot{V}) + 2927 \quad (22)$$

Where $\dot{\mathbf{V}}$ is the operating flow rate in m^3/s. Similarly, the operating cost of the expanders can be calculated, using the same expression as the compressors [5.5]:

$$C_{p0} = 124.813 \cdot (\dot{V} \cdot r) + 2927 \quad (23)$$

Where r is the characteristic volumetric expansion coefficient of the expander.
The cost of the heat exchanger can be estimated thanks to [5.6], which provides estimates per square meter. In particular, a purchase cost of 90 €/m^2 is estimated for a steel exchanger.
Once the purchase costs of the compressors, expanders and heat exchanger have been obtained, the purchase costs are multiplied by 1.18 to take into account the costs related to material, work and installation [5.1].

5.3 Second System: Cost Analysis

The second system consists of a compressor and a heat exchanger for cooling the gas in series. In this way the biomethane is sent to the pipeline, which will pour the gas directly into the network.
While the costs of the compressor and the heat exchanger are estimated as shown in the previous paragraph, the estimate of the gas pipeline is affected by numerous variables. In particular, the estimate depends on the length of the pipeline, the flow rate, and the complexity of the civil works. Due to the high number of variables, the cost of the pipeline can vary from 50 to 900 €/m [5.6]. In this regard, two different cost scenarios have been considered:

- 50 k€, order of magnitude of the cost of the pipeline in the absence of excavation and less than one kilometer long;
- 1 M€, order of magnitude of the cost of the pipeline in the event of excavations and a distance between the plant and the network between one and two km.

5.4 Economic Analysis

Once the costs have been estimated, it is possible to use the NPV method, to evaluate and compare investments:

$$NPV = -I + \sum_{i=1}^{n} \frac{(-C_{OpEx,i} - C_p + R_i)}{(1+j)^i} \tag{24}$$

Where:

- I: is the initial investment;
- C_{OpEx}: refers to the operating expenses to be incurred on an annual basis;
- C_p: biomethane purchasing cost;
- R_i: annual revenues;
- J: Discount rate.

To estimate the risk associated with the investment a profitability index is used:

$$PI = \frac{I + NPV}{I} \tag{25}$$

The higher the value of PI, the less risky the investment.

5.5 First System Economic Evaluation

By applying the methods for the evaluation of costs and investment introduced in the previous paragraphs, it is possible to draw conclusions regarding the economic feasibility of the construction of the liquefier, from the perspective of Petrolbitumi srl. In the evaluation of the investment, from an operational point of view, the company has the role of liquefying biomethane. Consequently, the company purchases the biomethane produced by the plant, and follows the liquefaction process. After that, a third party will handle the transportation of LNG.

The value of the investment (Capex) is quantified by summing the estimated value of the machinery using the method described in paragraph 5.2.1. The investment therefore amounts to approximately 1.3 million euros.

Operating expenses (Opex) correspond to 2.5% of Capex [5.7]. The Opex are distributed as follows:

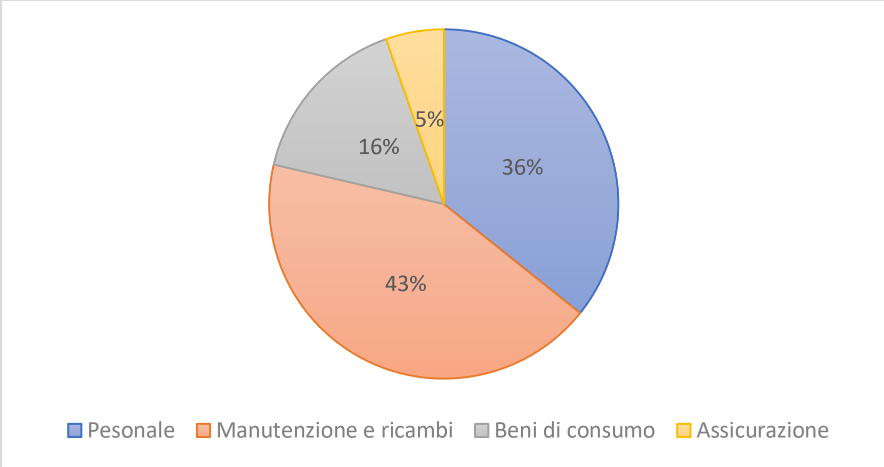

Figure 5.3 Opex Distribution

As regards the purchase of biomethane from the production plant, the literature estimates a production cost of the same equal to € 0.54 m^3 [5.8, 5.9], which corresponds to € 0.77 / kg. On the production cost of adds a margin that in percentage terms brings the same value to both parties.

Since the distribution of LNG is handled by third parties, a transport cost is associated from the liquefier to the plant. In this regard we estimate a cost of € 90 per day, assuming a distance of 60 km a week, which amounts to € 22,500.

The energy consumption of the liquefier in Figure 5.2 corresponds to 0.75 kWh / kg. Multiplying for annual production in kg and for the average cost of energy which corresponds to 0.13 € / kWh, an energy cost of approximately 188 k € is obtained, the most important cost item to weigh on the economic evaluation . It is in fact possible to carry out a sensitivity analysis to observe the variation of the NPV according to this item.

The revenues of the liquefier derive instead from the sale of the LNG itself. The market price is assumed to be equal to that proposed by ENI, ie € 0.97 / kg. Knowing the nominal hourly production of the plant, which stands at 333 Nm3 / h, an annual bio-LNG production of almost 2000 t / year is obtained, considering an average biomethane density of 0.7 kg / m3.

The second source of revenue corresponds instead to state subsidies. As already introduced, the grant is paid in the form of certificates of entry for consumption (CIC). The total grant amounts to 70% of the total investment.

The graph in Figure 5.4 represents the NPV trend as a function of time. In particular it is noted that the growth of the NPV is quite fast in the first three years thanks to state subsidies. The NPV becomes positive during the eighth year and has a final value of 384 k € at the end of the twentieth year.

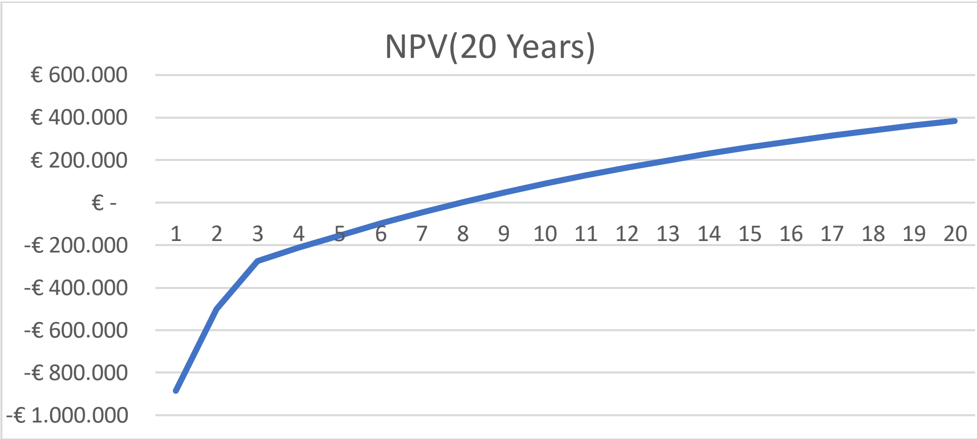

Figure 5.NPV on a 20 year base, distributor perspective

The value of the PI index is around 1.3, showing a medium risk value consistent with the value of the investment.
Carrying out a sensitivity analysis on the NPV value as the energy cost changes, which affects more heavily than the other items. This without considering the annual purchase cost of biomethane, which is based on a fixed price. The same evaluation can be carried out taking into consideration the IP, the risk increases if the NPV is zeroed, that is, around 0.16 € / kWh.

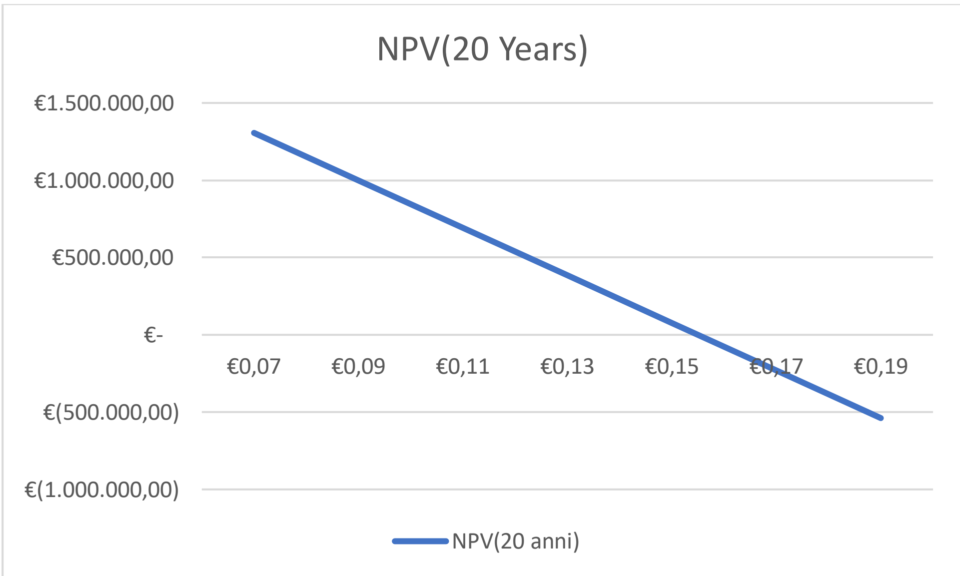

Figura 5.5 NPV in function of the energy cost[€/kWh]

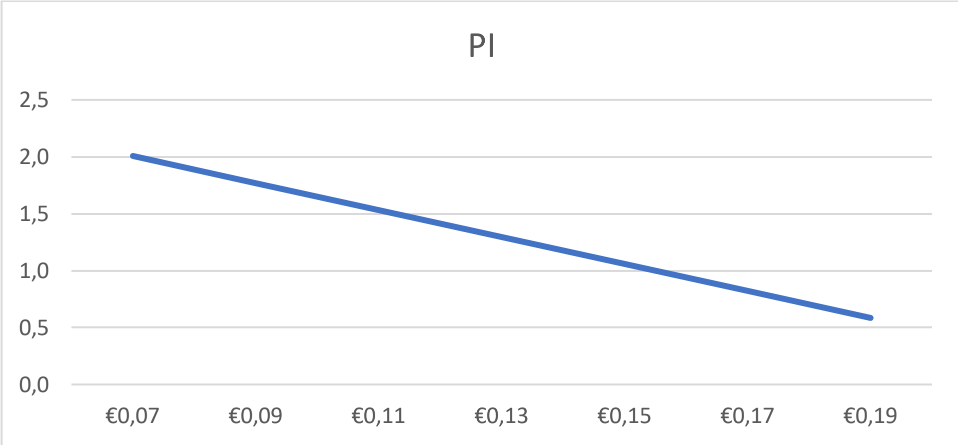

Figure 5.6 PI in function of the energy cost[€/kWh]

5.6 Investment from the Producer's Perspective

The analysis in this paragraph refers to the case in which the investment is made directly by the biomethane producer. The perspective changes with respect to the previous case, since the manufacturer is faced with lower costs but the same is true for revenues. In fact, the manufacturer finds himself having to sell bio-LNG to a distributor at a lower price than the final sale, which stands at € 0.97 / kg. The price charged by the producer to the distributor is therefore considered as a variable, as this price is decided during the negotiation between the two parties.
As for the costs faced for liquefaction, the producer bears the costs for the production of biomethane and those related to the energy consumption of the liquefier. The distribution costs of bio-LNG are instead borne by the distribution company.

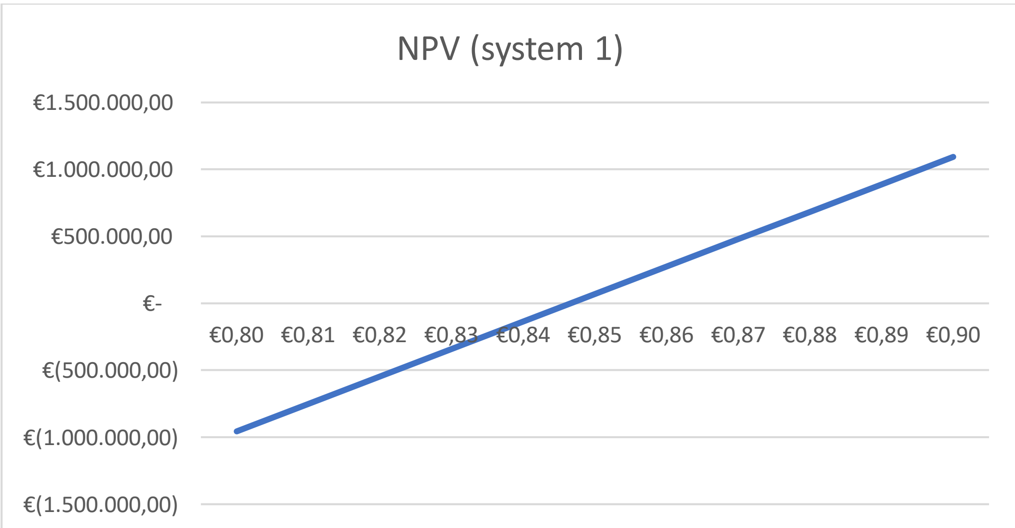

Figure 5.7 NPV in function of the contracting cost[€/kg di GNL]

As can be seen from Figure 5.7, a retail sale price of € 0.85 / kg makes the investment attractive, but we must take into account the risk the producer bears:

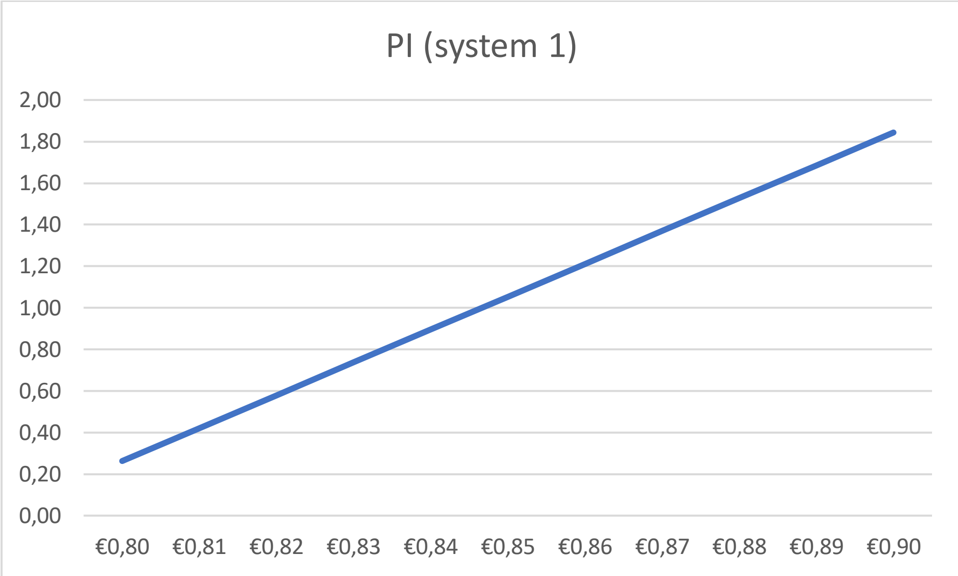

Figura 5.8 PI as the contract price changes [€/kg of GNL]

5.7 Second System: Economic Evaluation

In this analysis the producer decides not to invest in the liquefier, but to send all the gas produced on the network directly. The performance of the NPV depends strictly on the value of the initial investment, as described in paragraph 5.3. The two cases are represented respectively by the orange curve, if we consider a cost of 50 k € for the pipeline and the blue curve, if we consider instead a cost of 1 M €. Analyzing the graph, we observe that in the range identified by the two curves, the NPV values are localized for investments between the two extreme values. The worst case, that in which the initial investment amounts to € 1 million, presents an attractive situation even if with a considerable level of risk.

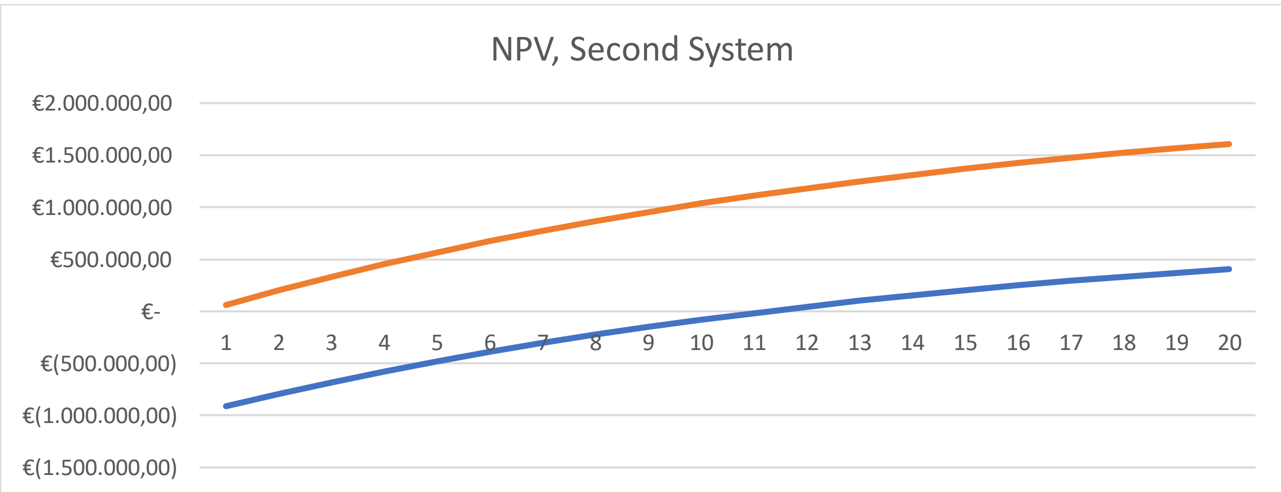

Figure 5.9 System 2 NPV, as the initial investment changes

5.8 Comparing the Two Investments Alternatives

The comparison between the two cases is made by calculating the difference between the NPVs of the two investments:

$$\Delta NPV = NPV_{system1} - NPV_{system2} \tag{26}$$

The expression (26) is represented in Figure 5.10 in graphic form. Since the agreed price between producer and distributor is a variable (on the x-axis) two expressions have been plotted: in blue the difference between the NPVs of the first system and the second with an investment of 50k €, in orange the difference between the NPVs of the first system and the second with an investment of € 1 million. The graph shows that there is convenience in making the liquefier if the price negotiated between the two parties for the supply of bio-LNG is higher than € 0.85 / kg.

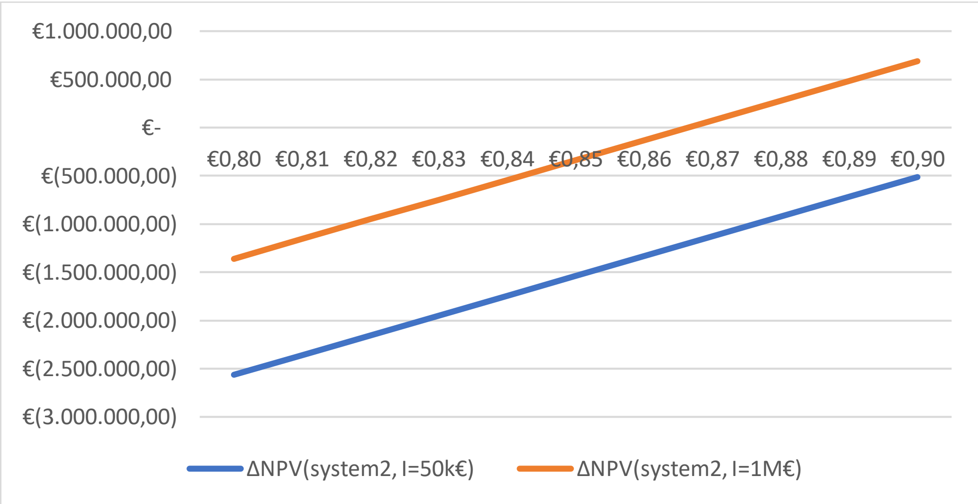

Figure 5.10 ΔNPV as the contracting price changed [€/kg of GNL]

Instead, the risk associated with the two investments is compared through:

$$PI_c = \frac{PI_{system1}}{PI_{system2}} \tag{27}$$

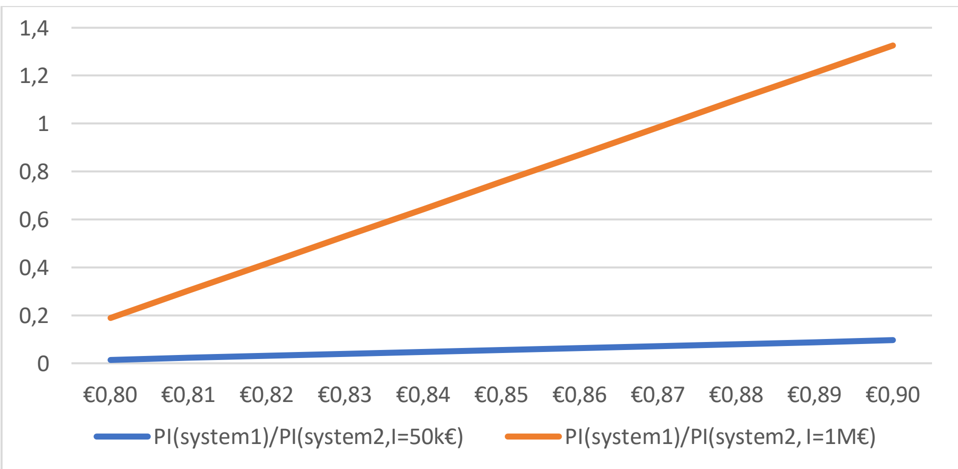

Figure 5.11 PI of the two systems based on the contract price [€/kg of GNL]

The graph in Figure 5.11 shows that the investment relating to the second system with a pipeline cost of € 50k is not very risky compared to the liquefier, canceling the fee. The two investments, on the other hand, offer comparable risk profiles for price values above 0.88 € / kg, if the second system is considered, with an investment of 1M €.

5.9 Fuel Cost Reduction

The presence of a liquefier near service stations benefits the company that sells fuel. This is because, as explained in the previous chapters, the absence of a terminal in Italian ports with the infrastructure suitable for taking LNG forces the withdrawal to the Marseille terminal at Fos Sur Mer.

In addition to the benefits deriving from geographical proximity, the production of bio-LNG would benefit in terms of competitiveness. In fact, being that of fuels a very competitive market, there would be the possibility of reducing the price compared to that of competition in the light of a higher margin on bio-LNG compared to that on LNG. Furthermore, it must be considered that the price of bio-LNG is not indexed unlike that of LNG, avoiding price fluctuations. This implies a lower risk on the purchase of bio-LNG.

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Chapter 6

Diesel Fleet Conversion to LNG

As already shown in the third chapter, European governments struggle against old-technology diesel engines, banning the entry of polluting vehicles into city centers. Subsequently the speech was extended to the trucks crossing the motorways, starting from the Brenner one. Despite this, several factors have helped to incentivize companies to start replacing fleets. In particular, this chapter will show the factors that contribute to the change, starting from the fact that the trucking fleet in Italy is obsolescent. Moreover, it is possible to demonstrate the economic convenience, supported also by incentives offered by the state. Those who decide to convert diesel fleets to LNG evaluate their investment mainly in terms of the difference between the price of diesel and that of LNG. As a result, while the initial outlay is higher for the LNG truck, this is recovered over the years thanks to lower fuel costs. In the first paragraphs of this chapter the current status of the Italian heavy vehicle fleet is shown, which is in a situation of obsolescence. Following are explained the incentives that the state offers to those who decide to renovate their park. Along with the environmental purpose, these are two other factors that lead Italian companies and municipalities to convert their fleets. Before starting with the accounts, specifically all the factors that influence purchasing decisions are analyzed, which contribute to increase the total cost of ownership (TCO).

6.1 Operating Fleet Current Status

In 2017 in Italy the fleet of goods transport trucks counted 4,083,348 units. This is the highest value ever since the beginning of the economic crisis, i.e. since 2008, when the fleet of goods transport trucks numbered 3,914,998 units. In the first phase of the economic crisis, or in the period between 2008 and 2011, there was a growth, albeit modest, of the circulating fleet of trucks. In this period, in fact, the park went from 3,914,998 units in 2008 to 4,022,129 units in 2011, with annual growth rates of around 1%. Since 2011, however, the picture has changed when the economic recovery has stopped and the second phase of the crisis has begun, which has also penalized truck sales. This caused a decrease in the number of vehicles in circulation with the return already in 2012 below the threshold of 4 million vehicles (-0.8% compared to 2011), a contraction which then followed in 2013 (-1.3%) and in 2014 (-0.2%).

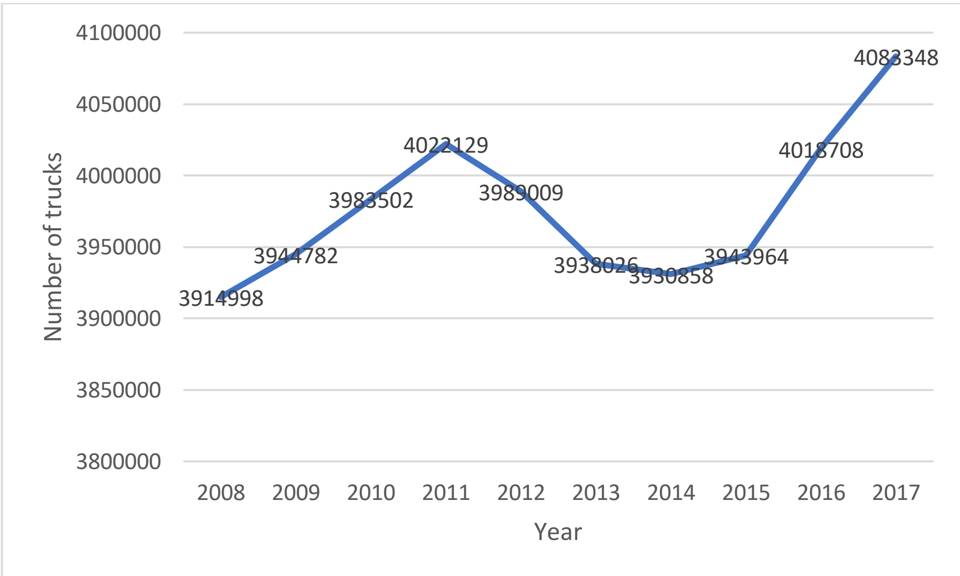

Figure 6.1 Heavy vehicle fleet evolution[6.1]

Only since 2015, with the improvement in the economic situation, the park has started to increase again (+ 0.3%) and in 2016 has recovered the pace of pre-crisis growth (+ 1.9%) and has returned to exceed the threshold of the 4 million vehicles. As stated above, in 2017 this growth continued to bring the park to a record high of 4,083,348 units, which represent the highest level since 2008.

In 2017, the region in which these vehicles grew the most is Trentino Alto Adige, with an increase of 15.1%. Second place is followed by Valle d'Aosta (+ 12.4%), and then again Basilicata (+ 2.6%), Molise and Puglia (+ 2.2%), Tuscany and Sardinia (+ 2.1%) . At the end of this ranking there are Piedmont and Emilia Romagna (+ 0.4%) and Lazio (-3.2%).

Despite the growth of the fleet of lorries, the freight transport sector in Italy continues to have a strong need for a replacement of an old-fashioned vehicle fleet, which in the worst years of the crisis due to obvious economic difficulties transport companies preferred to put off. This need responds to the need to combine cost containment with ever-increasing attention to environmental issues.

6.1.1 Operating Park Obsolescence

Out of a total of 4.8 million trucks in circulation, those belonging to the Euro 0, 1, 2 and 3 emission categories represent the majority and are 2.7 million, equal to 56.6% of the total. The Euro 4, 5 and 6 trucks are 2.1 million, or 43.4% of the total.
The region where there is the largest percentage of pre-Euro 4 trucks is Calabria (76.4%), followed by Sicily (73.5%), Basilicata (70.5%) and Campania (69.5%). The most virtuous regions, on the other hand, are Valle d'Aosta and Trentino Alto Adige, where 19% and 21.6% of the circulating trucks are, respectively, before Euro 4.
The situation therefore shows the picture of an old vehicle fleet (Table 6.1), but which represents an opportunity. In fact, the trucking companies that need to upgrade their fleet must also consider new technologies.

Table 6.1 Share% of trucks before Euro 4 per region [6.2]

Calabria	74,6	Marche	59,9
Sicily	73,5	Liguria	55,3
Basilicata	70,5	Friuli VG	54,7
Campania	69,5	Piedmont	53,4
Sardegna	68,8	Emilia Romagna	53
Molise	66,8	Veneto	51,8
Puglia	66,7	Tuscany	46,7
Abruzzo	63,8	Lombardy	45,8
Lazio	60,6	Trentino AA	21,6
Umbria	60,6	Valle d'Aosta	19

6.2 Incentives Provided for the Purchase of a New Truck

Through the Decree of 5 July 2018, the Ministry of Infrastructure and Transport allocates € 33.6 million to renovate the vehicle fleet. The Decree of 20 April 2018, on the other hand, governs the methods for disbursing resources for investments of 33,600,000 euros and their distribution, specifically:

- € 9.6 million for the acquisition (also through financial leasing) of new factory vehicles, with methane, LNG, hybrid (diesel / electric) and electric (full electric) traction. The vehicles must have a total mass at full load of 3.5 tonnes or more;
- 9 million for the scrapping of heavy vehicles with a total mass at full load of 11.5 tons or more, with the simultaneous acquisition of new Euro 6 vehicles;
- € 14 million for the acquisition (including through financial leasing) of new factory trailers and semi-trailers for combined rail transport (complying with UIC 596-5) and for combined maritime transport equipped with ship hooks (complying with IMO regulations) . Resources are also available for the acquisition of trailers and semi-

trailers or equipment for specific motor vehicles greater than 7 tons, set up for transport under the ATP regime (perishable foodstuffs), meeting advanced energy saving and environmental compliance criteria;

- 1 million for the acquisition (including through financial leasing) of swap bodies and trailers or crate carrier trailers.

For the purchase of CNG and LNG vehicles the contribution is:

- 4,000.00 for each CNG alternative natural gas vehicle, with a total mass at full load equal to or greater than 3.5 tons and up to 7 tons;
- € 8,000.00 for each vehicle equal to or greater than 7 tons up to 16 tons;
- € 20,000.00 for each vehicle with a mass LNG of 16 tons or more.

The incentives are payable up to the resources available for each of the types listed above. In the event that the resources are not sufficient, the contributions are proportionally reduced among the accepted amounts.
The maximum amount per individual company cannot exceed 750 thousand euros.
The deadline for submitting the application dates back to April 15, 2019, but at a meeting held on May 16 for 2019, MIT confirmed an allocation of 25 million euros as incentives for the purchase of new vehicles and trailers for the three-year period 2019-2021, broken down as follows:

- € 9.5 million are intended for the purchase of LNG powered vehicles;
- € 9.0 million for the scrapping of old vehicles with the simultaneous registration of new members of the Euro VI ecological class;
- € 6.0 million for the purchase of trailers and semi-trailers for intermodal transport on ships or trains;
- € 0.5 million for the purchase of swap bodies.

6.3 Fleet Conversion

In 2019 the number of requests for LNG truck incentives was in excess compared to the amount envisaged by MIT. For economic reasons and to comply with EU environmental standards trucking companies and Italian municipalities have decided to convert their fleets. In particular, Sanpellegrino has completely replaced its fleet. In this case, a cryogenic deposit was installed near the production plant, along with two LNG service stations near the plant .Similarly, Contarina spa, which deals with the management of environmental services in the province of Treviso, has decided to invest in a point of storage and supply of LNG and CNG for its vehicles. In this case, the plant under construction is fed by the biogas produced by Contarina itself.Another virtuous case is that of Bologna, in which Hera supplies 4 buses and 20 taxis via a CNG service station. The latter is connected by piping to an advanced biomethane production plant.As you can see from these two last examples, the first investors are subjects that act as demonstrators of the functionality of the business. This increases the confidence of small investors in the new model, as well as bringing citizens and society closer to a new supply system that increases their quality of life.

6.4 A New Truck Purchase Evaluation

Companies that buy new long-haul trucks find themselves having to compare different technologies before making the purchase. Consequently, it is necessary to take into consideration the alternative to LNG, to counteract the diesel one. To perform this comparison it is possible to use the total purchase cost (TCO), which represents the cost that an asset generates during its entire life, considering both the initial investment and the management costs. For example in the case of a truck, the TCO takes into consideration:

- Purchase Method
- Fuel
- AdBlue
- Employees
- Maintenance and repairs
- Toll pike roads and taxes

Purchase or lease - The choice between purchase or lease is dictated by innumerable factors: not only the initial investment, but also the long-term investment should be considered. In Italy a truck that travels long distances, with particular reference to medium and heavy trucks, has an average life span ranging from 16 to 19 years, with mileage of millions of kilometers.
Leasing is cheaper for fleets with lower purchasing power, because with a lower initial cost, capital can be better protected and protected against unexpected costs. Having recent vehicles also means having vehicles with reduced engine and other components subject to average wear, therefore, on average, the fleet will be more efficient than those with more kilometers on their shoulders.
The decision to buy instead may be the right choice for companies that want to increase the value of their assets. If you look at the used car market, the age of a truck could determine, despite a lower purchase price, TCO higher than that of a newer and more expensive truck, due to the lower efficiency in terms of consumption and increased wear on components [6.3].

Maintenance - It is noted that on average the recommended distance between the houses, between one maintenance and another, is about 24,000 km [6.4]. One of the aspects in this regard is lubrication: it is able to protect mechanical components (engine, gearbox, transmission) from wear, significantly improving useful life and reducing consumption due to less friction. As for tires, a regular control of pressure and wear can have a direct impact on consumption and therefore on operating costs.

Evolving technologies - The introduction of new standards leads to the development of all technologies aimed at reducing consumption, with consequent benefits relating to emissions. The new standards impact fleet operating costs, gradually reducing the mileage costs of their fleets (net of fuel costs) [6.5]. This opens up the possibility of choosing the means more accurately during the purchase phase, with the introduction of comparison tables on actual consumption, provided for by the new legislation. These improvements on combustion, aerodynamics and weight reduction affect the lowering of TCO.

Fuel - The development of engines makes the use of alternative fuels such as methane (CNG - compressed natural gas) or LNG (liquefied natural gas) increasingly interesting. However, this decision must be drawn up by fleet managers in a long-term context. Even if the immediate cost of alternative fuels could be lower, it is important to calculate the weight of this amount on the total cost of operation, since other costs (for example those for refueling or disposal) could ultimately make this option less advantageous.

Personnel - In addition to the technological aspects of vehicles, it must be remembered that the human factor always remains the most important. Common sense in speed moderation, smooth driving with reduced accelerations and decelerations and the correct choice of gear ratio are parameters that can have a big impact on fuel consumption. ExxonMobil reports, for example, that reducing the speed from 90 km / h to 80 km / h can reduce fuel consumption by up to 22%, a considerable value when compared to an entire fleet.

End of life - The end of life of the vehicle affects the total cost of the operation, therefore the relative costs must be considered already in the purchase phase. If it is no longer possible to transfer the vehicle to an external subject, because the vehicle is no longer usable, among the various disposal hypotheses, scrapping programs exist, promoted directly by the manufacturers, in line with the increasingly stringent regulations aimed at proper disposal ecological. In fact, a regulatory battle is taking place to hinder the export of end-of-life vehicles outside the EU and to promote instead the scrapping and recycling of metals within the European community itself, giving benefits in economic terms to those who choose this path.

3.1.2 Case Study: a New Truck Purchase

In long-haul heavy road transport, the use of LNG as an alternative fuel to Diesel is also based on its economic sustainability. Economic sustainability is due to its lower cost for the same energy content, which must at least offset the higher costs associated with the specific technology.
The purchase or transformation price of a LNG vehicle compared to a conventional Diesel vehicle equivalent varies from € 15,000 to € 60,000 [6.6].
In addition to the higher cost of the specific engine and fuel system components, in the order of 5,000 ÷ 30,000 €, the second most important cost for a LNG vehicle is the fuel storage system [6.7]. The use of LNG increases the autonomy with respect to CNG while maintaining the advantages in terms of reduced emissions compared to diesel. The liquid state allows, for the same volume, distances approximately 2.5 times longer with respect to those of CNG, and slightly less than half compared to diesel [6.8].

In particular, it is possible to evaluate the economic convenience by considering two trucks with similar power, one diesel and one LNG respectively.

Table 6.2 Comparison of data on diesel and LNG trucks

Extra-cost[€],	0	67398
Consumption [km/l]	3,63	3,96
Fuel cost[€/l]	1,47	0,979
AdBlue[% of fuel cost]	2%	0
Saving [€/km]	0	0,19

By re-processing this data it is possible to determine how many years or kilometers are required for the investment to be equal from an economic point of view:

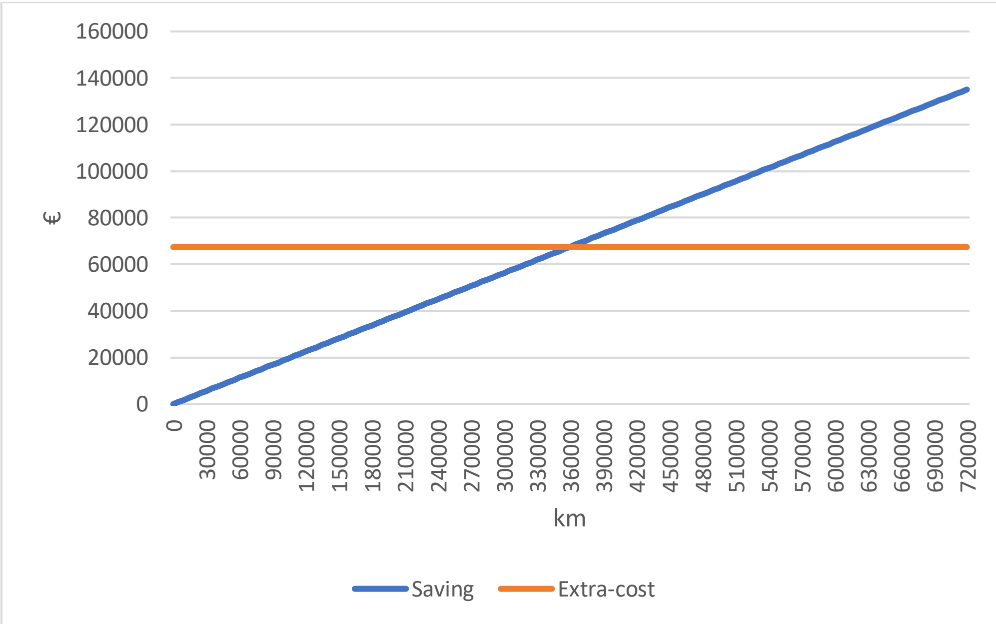

Figure 6.2 Comparison of diesel and LNG truck purchase

An investment in a LNG truck is therefore convenient if the total minimum mileage of the truck is greater than 360,000 km. If we plan to cover around 120,000 km / year, this means that it is possible to obtain advantages in terms of savings after at least 3 years.

Since economic sustainability mainly depends on the annual mileage and the price difference between diesel and LNG, a cost difference of € 0.15 between Diesel and LNG represents the break-even point for the transporter [6.9].

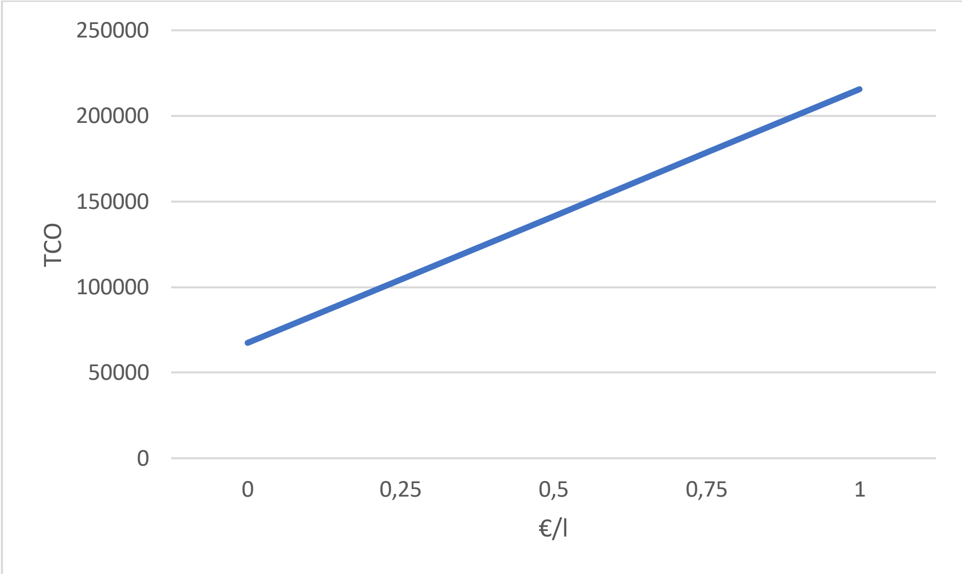

Figure 6.3 TCO as fuel price changes vary [€/l]

The savings values take into account all the negative contributions (purchase cost of the vehicle, associated financial costs, maintenance, residual value).
To take into account the fact that to date there is only one LNG truck marketed by Iveco, but as the number of trucks entering the market increases, the price will decrease, approaching that of the corresponding diesel model. Other manufacturers, like Scania, Volvo and Mercedes, are in fact preparing to offer their LNG models to the market.

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Chapter 7

CO_2 Emissions Reduction

Over the years, environmental issues have become increasingly central, both in the definition of Community Directives and in the design of national development plans, interpreting the need to define measures to guarantee energy security through a more efficient use of energy and of resources. The main aspects of the environmental theme are based on the evaluation of anthropogenic impacts, specifically linked to the aspect of climate change and air quality.

On a global level, the theme was first discussed in Rio de Janeiro in 1992 in the United Nations Convention on Climate Change, signed by 154 countries whose ratification committed governments to pursue a "non-binding objective" to reduce atmospheric concentrations of greenhouse gases with the aim of "preventing dangerous anthropogenic interference with the earth's climate system". From that moment, the signatory States met annually in the Conference of the Parties (COP) to analyze the objectives set and to redesign the strategies to be pursued to face the phenomenon of climate change: from the famous Kyoto protocol, the recent agreement was reached Paris (COP21), where in 2015 the 195 signatory countries adopted the first legally binding global climate agreement, defining a global action plan aimed at tackling the issue of climate change by limiting global warming to below 2 ° C. The strategies and development plans identified in Paris were then confirmed at the last meeting in Katowice, dated December 2018.

This chapter aims to assess the impact of greenhouse gas emissions through a "Well to Wheel" analysis. The analysis is supported for diesel engines, LNG and bio-LNG, so as to be able to sustain a comparison.

7.1 Purpose of the LNG Well to Wheel Analysis

This chapter aims to provide a picture of the intensity of contributions from the natural gas sector in terms of greenhouse gas emissions, for the various sectors heavy road transport through an analysis "from the well to the wheel".
The various contributions deriving from CO2, CH4 and N2O emissions have been integrated to quantify the effects related to the issue of climate change. By combining each character with its own characterization factor, and aggregating the individual contributions, the global warming potential (GWP) is defined, also known as greenhouse gas intensity or Carbon Footprint, expressed in CO2 equivalents (CO2 eq). In the study, the analysis from the well to the wheel is divided into two segments: in the first, the contributions from the well to the tank are determined (Well to Tank, WtT), specifically analyzing the different phases of extraction, processing and supply; the second is instead focused on the path from the tank to the wheel (Tank to wheel, TtW).
In the graphical representation of the flow diagrams (Figure 7.1) the structure of the study is summarized: the subdivision in this case takes into consideration exclusively the LNG supply chain, omitting uses of the LNG for ships, trains.
The "Well to Whell" index, expressed in Mega Joules per km, is divided into two sub-indices: the "Well to Tank" and the "Tank to Wheel". The first sub-index refers to the energy costs associated with the processing of the primary source, ie extraction, processing and transport. The second sub-index refers to those related to propulsion technology (diesel engines, LNG and bio-LNG).
Finally, the WtW analysis on the LNG supply chain, described through the GW, represents potential impacts and not actually observed. The results presented do not predict real impacts, but express environmental effects such as global warming.

7.1.1 LNG Well to Tank Analysis

"Well to Tank" is the first analysis that makes up the "Well to Wheel". We consider all the elements that make up the LNG supply chain starting from production, up to tank (i.e. the distributor), with the aim of determining all the greenhouse gas emissions in terms of CO2-equivalents. To this end, the boundaries that delimit the system are analyzed first of all.

7.1.1.1 WtT System Boundaries

The analysis aims to consider greenhouse gas emissions starting from the "well", ie the gas production point, up to the "tank", which coincides with a distribution point. The boundaries of the system taken into consideration are described schematically in Figure 7.2.

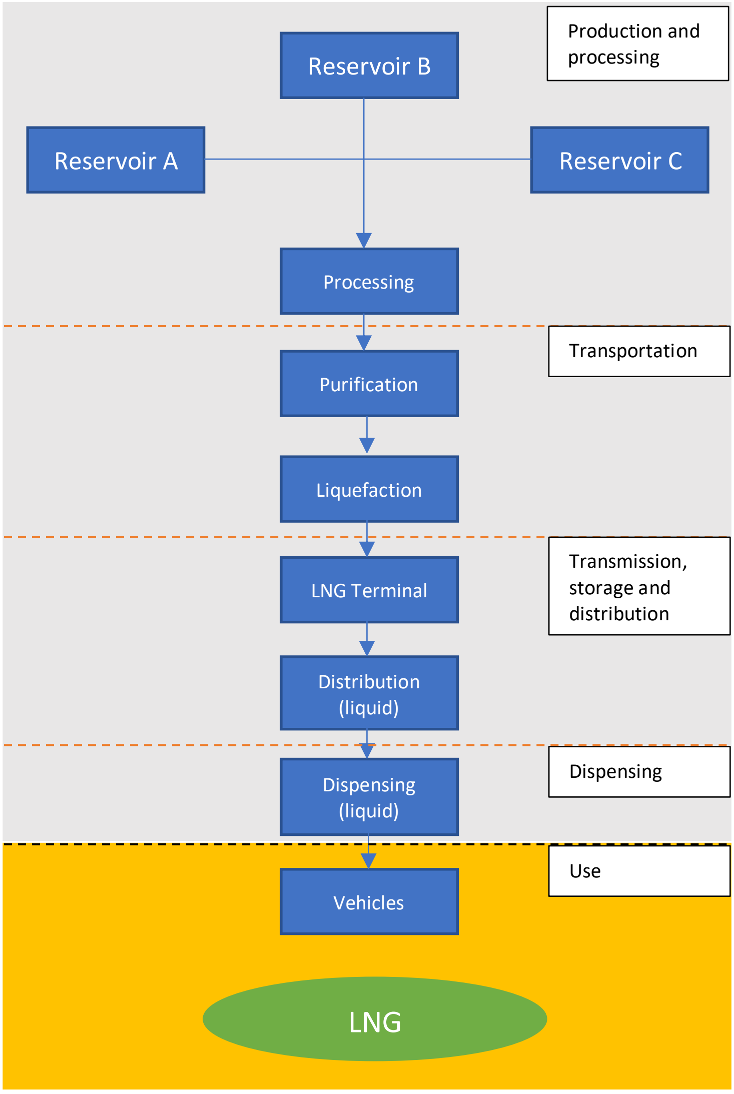

Figure 7.2 WtW system boundaries

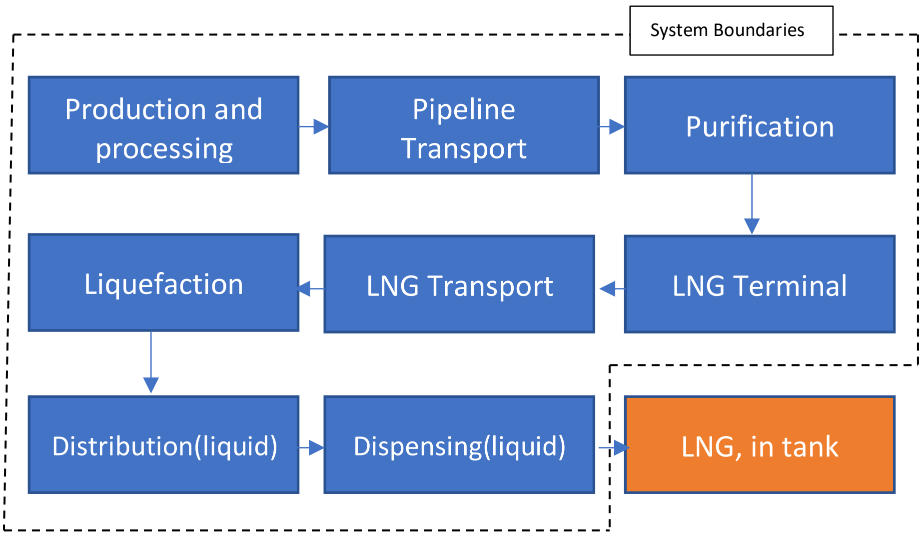

Figure 7.3 WtT System boundaries

The term production refers to the fact that it is necessary to perform drilling work to recover the gas. This happens with regard to natural gas. In fact, in the case of unconventional gas (such as "shale gas"), the term production refers to all the procedures necessary for the transformation of the raw material into gas. After the production phase, ie after the extraction of the "rich gas". A purification process follows for the removal of water, carbon dioxide and hydrogen sulphide, from which "dry gas" is obtained. After that, the gas is introduced into a pipeline that connects production and purification. The structure is maintained at a constant pressure that allows the gas to travel. Compressors that maintain pressure can be powered directly by the gas flowing into the pipeline or by diesel engines. The gas goes directly to the liquefaction train via the pipeline. After being liquefied, the gas is introduced into a LNG vessel, which transports LNG to its destination. LNG is thus stored in a storage center in the arrival terminal, to then be taken from tankers and distributed locally.

7.1.1.2 WtT: GHG Impact

Below is shown an overview that describes the results in grams of CO2-equivalents per MJ delivered to the tank at a medium level for each European region.

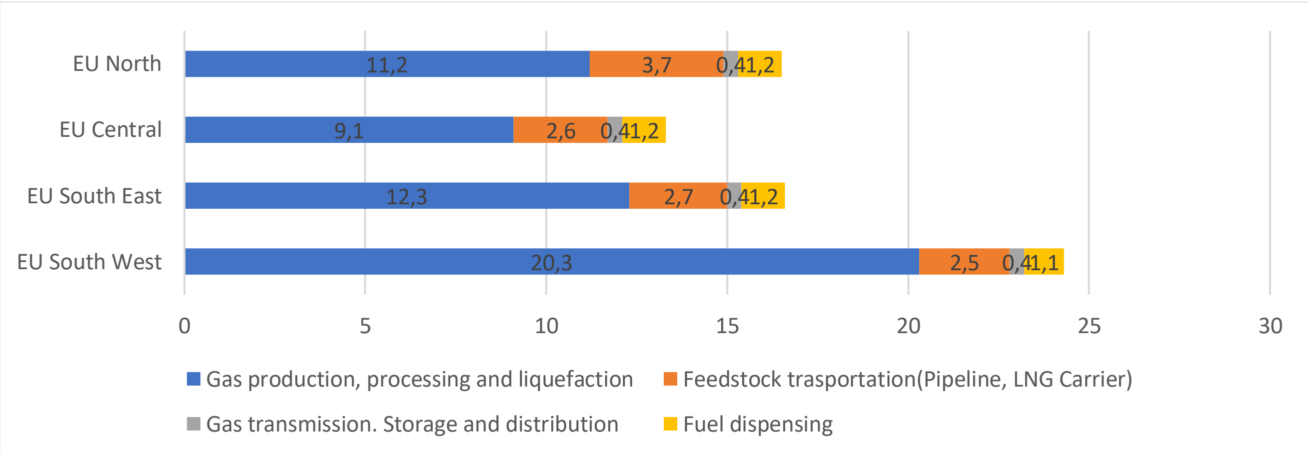

Figure7.4 WtT - LNG, in tank- GHG[g CO2-eq/MJ][7.1]

Table 7.1 Well-to-Tank – GHG Emissions: LNG supply – breakdown by main process steps [7.1]

[g CO2-eq/MJ], in tank	EU North	EU Central	EU South East	EU South West
Fuel dispensing	1,2	1,2	1,2	1,1
Gas transmission, storage and distribution	0,4	0,4	0,4	0,4
Feedstock transportation (Pipeline, LNG carrier)	3,7	2,6	2,7	2,5
Gas production, processing and liquefaction	11,2	9,1	12,3	20,3
TOTAL LNG	16,5	13,3	16,6	24,3

The data reported shows that the impact of carbon at the European average level is 19.9 g of CO2-eq / MJ. In particular, the bulk of the resulting greenhouse gases derive from production, purification and liquefaction, accounting for 77%. Transport by LNG instead for 15%, storage for 6% and distribution for 2%:

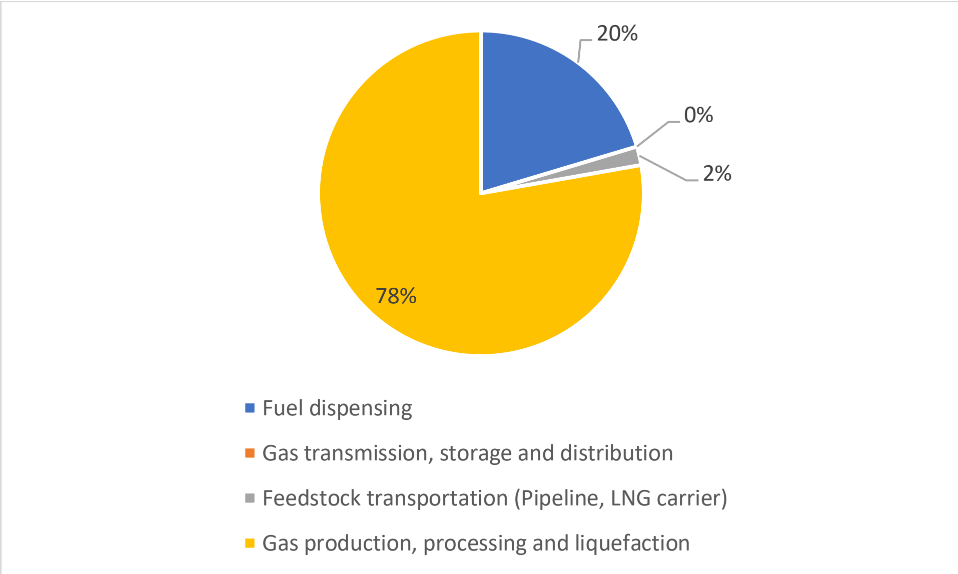

Figure 7.5 WtT-EU average- LNG, in tank- Methane emissions [g CO2-eq/MJ][7.1]

Some of the results shown in the table are very similar to each other since almost 100% of the imported LNG comes from Qatar.

It is possible to revise the table and the graph reporting the details regarding the emissions of CH4, N2O and CO2. The contribution of N2O is small compared to the other two gases, so its contribution has been omitted together with that of other climate-altering gases with a small impact.

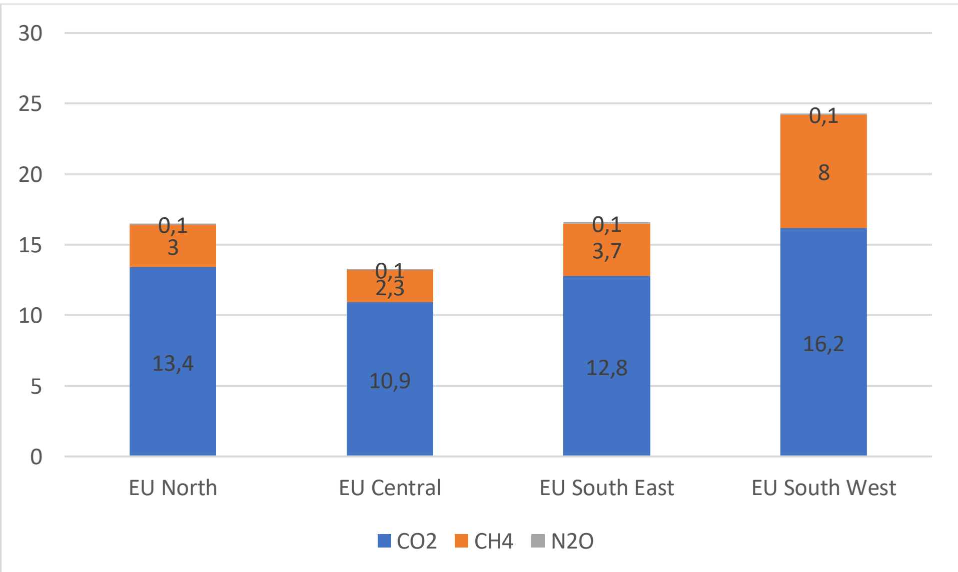

Figure 7.6 WtT-LNG, in tank - GHG by contributors [g CO2-eq/MJ][7.1]

7.1.2 LNG Tank to Wheel Analysis

In these paragraphs the concepts described in the "Well to Tank" analysis of freight transport are extended. The analysis considers 40t heavy transport vehicles, which travel a distance of one km with a full load of 75%.

7.1.2.1 TtW: System Boundaries

As shown in Figure 7.6, the "Tank to Wheel" analysis is less complex than the "Well to Tank" analysis. In fact, in this case the perimeter of the system coincides with the heavy transport vehicle that uses LNG as fuel. The study then evaluates all the CO2, N20 and CH4 emissions that occur during operations that relate to refueling and engine combustion processes. In this analysis, the production and disposal of vehicles is not considered.

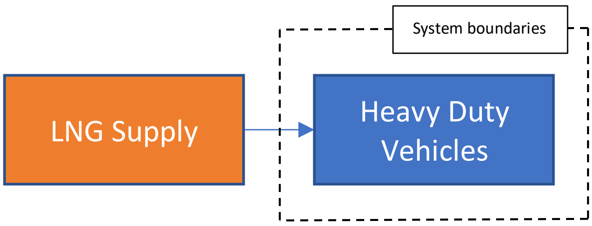

Figure 7.7 TtW System boundaries

7.1.2.2 TtW: GHG Impact

This analysis aims to determine the level of greenhouse gases per kilometer emitted by heavy transport vehicles. As previously mentioned, vehicles are considered for long-range transport with a maximum load of 40t, but 75% full. In this paragraph we will consider both diesel vehicles and LNG vehicles. For this purpose, the consumption of both types is verified, to then determine the amount of CO2 emitted by each vehicle per kilowatt hour. The latter data can be found on the manufacturer's website.

As far as CH4 emissions are concerned, it is possible to consider the maximum emission level envisaged by the Euro VI standard, which amounts to 0.5 g CH4 / kWh [7.2]. Despite this, the estimate presented is quite conservative and the engine manufacturers keep a lot below it, with the aim of reducing greenhouse gas emissions. For the determination of CH4 emissions, it was necessary to consider the efficiency of the engines [7.3], to then calculate estimates relating to CH4 emissions. In particular, for both engines an efficiency of 44.5% was taken into account, on an engine with an average output of 1.4 kWh / km.

As regards the estimate of N2O emissions, reference is made to the "WtW" analysis [7.4], in which these emissions are estimated as 5% of the maximum limit allowed by the legislation. These data are shown in table 7.2:

Table 7.2 Heavy-Duty Vehicles: fuel consumption, CO_2, CH_4, and N_2O emissions [7.1], based on [7.7], [7.8], [7.9], [7.10]

	LNG	Diesel
Fuel Consumption	26,7 [kg/100 km]	31,5 [l/100 km]
Energy consumption [MJ/km]	11,7	11,3
CO2 Emissions[g CO2/km]	659	827
CH4 emissions [g CH4/km]	0,349	-
N2O emissions [g N2O/km]	0,032	-

In LNG vehicles, natural gas is injected directly via a cryogenic pump into the combustion engine. Keeping the LNG in liquid form means keeping the vehicle tank at -162 ° C. The tank necessarily exchanges heat with the outside, determining the return to the gaseous state of a percentage of the liquid gas. This phenomenon is called "boil-off" loss. Losses of CH_4 due to "Boil-Off" are not released into the air unless critical pressure is reached.

7.1.3 LNG Well to Wheel Analysis

This analysis combines the results of the previous "WtT" and "TtW". In Figure 7.7 it is possible to observe that, at "Well to Wheel" level, the use of heavy LNG vehicles reduces greenhouse gas emissions compared to an equivalent diesel vehicle. In particular, a CNG vehicle reduces the level of emissions by 16% compared to a diesel, taking into consideration the entire supply chain. As for LNG vehicles, while the "TtW" analysis remains similar to that of the CNG, the situation is different for the "WtT" analysis in which the emissions are higher.

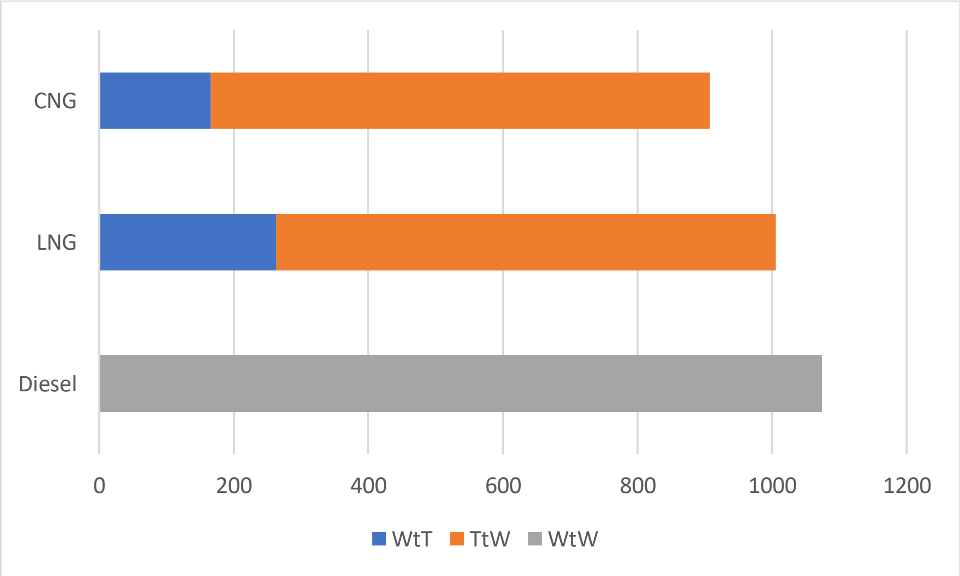

Figure 8.7 WtW-HDV-GHG[g CO2-eq/km][7.1]

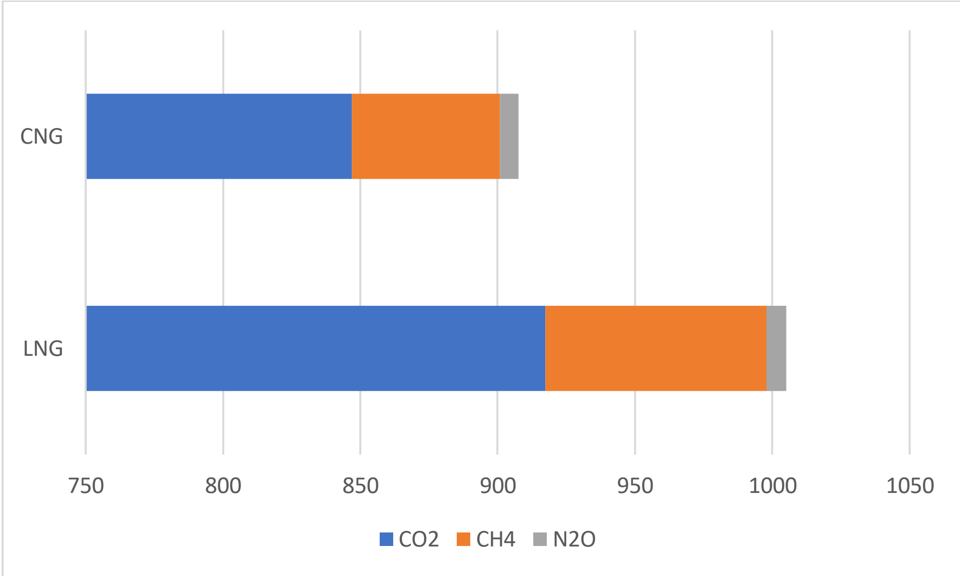

Figure 7.9 WtW-HDV-GHG by contributors [g CO2-eq/km] [7.1]

7.2 Bio-GNL Well to Wheel Analysis

In this paragraph it's initially considered a WtW analysis for biomethane production, and then extend it to bio-LNG production by introducing a liquefier within the boundaries of the system considered (Figure 7.9).The motivation for such a low impact of these renewable fuels compared to diesel lies in the fact that the CO_2 emitted is "carbon neutral": the emissions produced by the production process and along the entire supply chain do not exceed the planet's capacity to reabsorb them . As a result, these emissions were not taken into account in the studies [7.5.7.6]. Only biomethane, if replaced by diesel, reduces the emissions that cause the greenhouse effect by 80%, considering the entire WtW analysis. Instead, the situation for bio-LNG is different. In fact, the addition of a liquefier has a greater impact during production, increasing emissions in the WTT analysis. Emissions instead in the TtW analysis are buyable .In Figure 7.10, bio-CNG and bio-LNG mixtures are represented. In fact, to date there are no European data available on vehicles that use bio-CNG and bio-LNG due to the lack of infrastructure. The mixtures are both in a proportion 20% bio and 80% fossil. Despite this, the reduction of emissions represented by these solutions is evident. In particular, if one takes into account the use of 100% biofuels, with a simple proportion it would lead to a 77.5% reduction in emissions compared to diesel for bio-CNG and 77% for LNG.

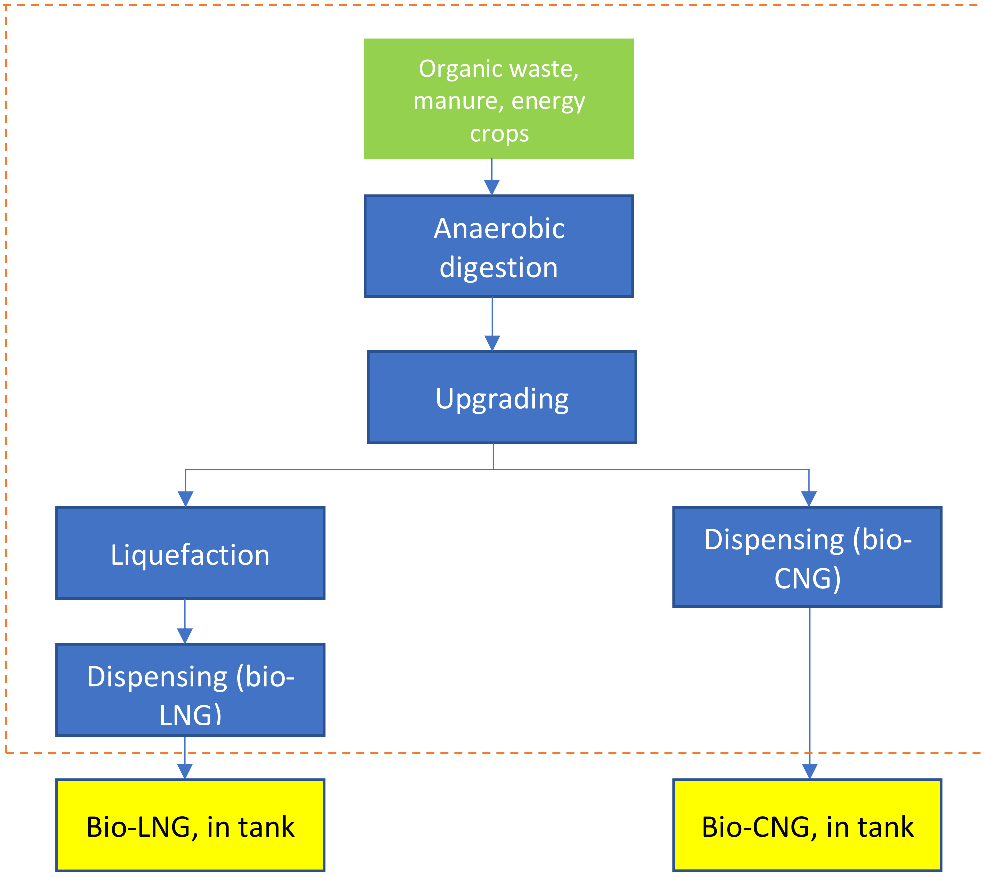

Figure 7.10 System boundaries for bio-CNG and bio-LNG WtT analyis

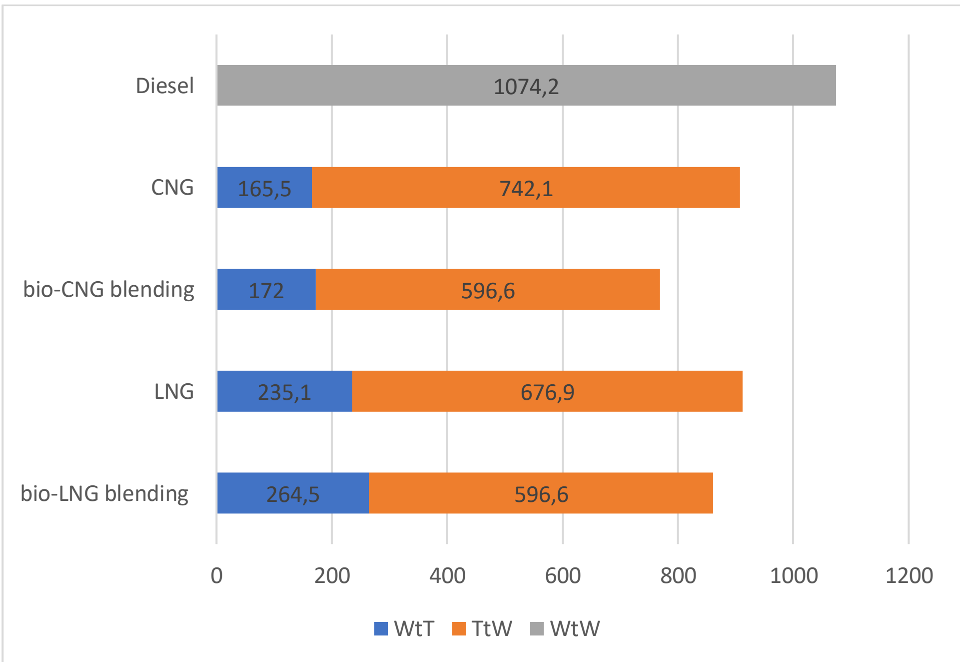

Figure 7.11 WtW-GHG emissions:HDV[g CO2-eq/km][7.1]

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Conclusions

In the field of fuels, bio-LNG is of interest for several reasons:

- It has exactly the same characteristics as LNG;
- It is produced using the wet fraction (FORSU) collected in urban centers;
- It greatly simplifies the logistics chain allowing an optimal management of stocks and confirms a competitive advantage by giving the possibility to the fuel distributor (in this case Petrolbitumi srl) to vary the price of fuel while maintaining a higher margin compared to competitors, which is instead they find themselves having to buy and import LNG from France.

Despite this, the emergence of bio-LNG is hampered by the possible investments made by large multinationals that produce energy. These investments, as burdensome, have the objective of updating the current regasification plants present in Italy so as to be able to supply LNG both to ships (bunkering) and to transport. Despite this, there are also cases in which logistics companies decide to convert their fleets from diesel to LNG, or to buy bio-LNG from new local producers at a fixed price.
The investor today decides to invest in bio-LNG if the size of the plant allows it, so as to benefit from economies of scale that proportionally reduce the costs associated with production, compared to a smaller plant. A similar argument can be made for logistics companies: a timid approach to fleet conversion cannot be decisive, especially when a competency is not created for the pilot who must learn to use the new technology.
Another assessment variable, from the point of view of the liquefier's investment, is the geographical conformation. The entrepreneur should invest in bio-LNG especially if he is in an unfavorable geographical area due to the presence of bridges, rivers and highways. The situation described above is actually quite frequent in Italy and represents a disadvantage if one invests in a pipeline for the biomethane input on the network but an advantage if one decides to liquefy it.
In general, the decision to inject biomethane directly into the network is the least risky choice, because it reduces the risk level of the investment. However, the other side of the coin reveals that we are giving up extra revenues.
As a result, there is room for reducing transportation costs for LNG as the investment is profitable. This is valid only if we consider the discourse of the bio-LNG, which represents an opportunity given the privileges in terms of competitiveness that it would offer to the distributor. In a more general perspective the realization of coastal deposits would decrease the transport costs for all Italian distributors, canceling the competitive advantages mentioned above.
Despite this, the LNG turns out to be the fuel of the future that accompanies a transition phase of unknown duration. In particular, the transition concerns the transition from diesel to a hybrid / electric technology that will even support long distances, which was the entire

drafting of the thesis. The results reported in chapter 6 are in fact incentives from the point of view of emissions, which are largely reduced if one decides to use bio-LNG.