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OPTIMIZING FUGITIVE METHANE EMISSIONS ABATEMENT: A NORMATIVE EFFICIENCY EVALUATION WITHIN THE ITALIAN NATURAL GAS DISTRIBUTION SECTOR

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Abstract

Methane is a potent greenhouse gas with a high global warming potential which expresses itself over short time horizons, posing significant challenges to global climate objectives. While extensive research has focussed on upstream methane emissions from extractions and production processes, the downstream distribution phase remains for the most part unexplored, yet crucial area for intervention.

This thesis addresses this research gap by investigating mitigation strategies dealing with fugitive methane emissions arising from the natural gas distribution sector, using the Italian network as a case study. Leveraging data from a leading Italian distribution company managing over 14.000 kilometers, serving more than one million customers, the study evaluates Company performances and practices against existing national and European guidelines and regulatory frameworks.

The aim is to address the environmental, economic, and social challenges of methane emissions in the natural gas distribution phase by identifying policy opportunities and proposing effective mitigation strategies. Using a mixed-methods approach, the research explores actionable policies and innovative strategies to mitigate methane emissions, with a holistic evaluation of the impacts.

The analysis reveals that aging infrastructure, material-specific vulnerabilities and inefficiencies in current practices are the main contributors to emissions. Prioritizing leak detection based on environmental impact can yield abatement benefits, albeit safety considerations and investment constraints must be addressed. Moreover, proactive leak detection emerges as a more effective strategy, highlighting the need for regulatory alignment and innovation incentives.

This study highlights the critical need for policy harmonization emphasizing stricter compliance measures to address methane emissions effectively. Financial incentives for technological innovation are essential to support detection efforts and additionally, enhanced citizen engagement mechanisms can improve detection rates and raise public awareness.

This can be achieved by adopting innovative policies and fostering collaboration among policymakers, distribution companies and end-users, immediate and lasting progress is achievable.

Mitigating fugitive methane emissions in the distribution phase represents a critical and actionable possibility to achieve climate goals, and this research offers clear recommendations for bridging the gap between technical potential and policy implementation, paving the way for swift impact and sustainable outcomes by identifying resource allocation efficiency as the main allied for climate action.

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Chapter 1 - Introduction: The importance of methane emissions abatement

1.1 Research question, methodologies and document overview

Methane emissions from natural gas distribution systems represent a critical challenge in the global achievement to mitigate climate change, and despite advancements in leak detection and repair technologies, fugitive methane emissions deriving from the supply chain of natural gas continue to impose environmental and economic costs. While existing research has extensively addressed upstream methane emissions, the downstream distribution network remains underexplored, particularly with respect to regulatory frameworks, practical mitigation strategies and the internalization of environmental costs. This thesis aims to bridge this gap by analyzing the Italian natural gas distribution network, proposing innovative intervention models, and evaluating their feasibility within the evolving European regulatory landscape.
The research question that serves as a ground for this document to arise is:

How can policies be optimized to efficiently prevent and address fugitive methane emissions in the natural gas distribution phase?

To address this the research delves into several connected subquestions:

- *What are the main reasons behind fugitive emissions during the distribution of natural gas?*
- *How can policy interventions mitigate these emissions efficiently?*
- *How do economic and environmental costs shape currently?*
- *What are the implications of different leak elimination strategies?*
- *What are the results related to an increase in leak detection?*
- *What is the role of citizens?*
- *Does the European Union move efficiently in the regulatory landscape?*

By addressing such questions the research aims to identify a coherent set of policy ideas and practices that balance environmental, economic and social priorities to adeptly tackle fugitive methane emissions in the natural gas distribution sector.
Existing literature mostly focuses on upstream operations, which are estimated to be the most threatening when it comes to the release of methane in the atmosphere; whereas the studies that do explore the distribution of natural gas tend to approach the topic broadly, or are technical documents redacted to aid companies in navigating the complexity of fugitive emissions estimation. From that stems a research gap, which the document describes, analyzes, and seeks to fill.
The objective of the document is to provide specific ideas related to the Italian natural gas distribution sector, developing a perspective of research that inquires into new priority frameworks for leak elimination, as well as a possible increase of citizen engagement in leak detection.
In order to accomplish that the document opens up with an introducing chapter describing global warming trajectories, driven primarily by greenhouse gas emissions, that are intensifying the urgency for immediate action to curb emissions.
Chapter 2 follows the introduction by giving a comprehensive view of the natural supply chain, from extraction to end-use with a later focus on the Italian supply chain and a first glance at the Italian current practices for monitoring, reporting and verification of fugitive methane emissions along the distribution of natural gas, paired with the economic costs evaluation related to the loss of natural gas and methane.

Chapter 3 deals with framework and estimation techniques and the explanation of the delta in-out, the difference between the input values of a network and the amount of natural gas exiting that network, how this represents a challenge for the quality of the service and how it is not a reliable way to estimate the methane emissions of a certain network. Such introductory part is followed by the overview of the current emission estimation for an Italian distribution company, focused on differentiating the existence phases of a leak, in order to generate separate estimates for further analysis and to quantify the impact of the various phases.

New models are proposed to prioritize leak repairs based on environmental impact, incorporating first budget constraints and later safety considerations, in order to analyze if there are possibilities to abate emissions by changing the priority of leak repair.

The models, paired with a current emissions estimation developed through data gathered from a leading Italian company in the natural gas distribution sector, will provide a comparative view in understanding how the analyzed policies could help increase efficiency in policy making and operational procedures aimed at abating fugitive methane emissions.

The analysis continues with a leak detection practices examination with a study of the current leak detection operation and the management of third party notification, economic transfers study and description, as well as criticalities of such.

Later the European regulatory landscape is introduced with a view of current climate targets and the development of ad-hoc regulations targeting fugitive emissions arising from the distribution network, paired with a qualitative and quantitative analysis of such.

Description of the methodological approach regarding data collection, work with the company, analysis of datasets and why such data has been collected by the company as well as data lacking, analytical techniques used for the modeling and the data analysis and the framework used as well as a brief introduction of the calculation made for the emissions estimations.

Brief thesis outline with a chapter overview and the contents, underlying the connections between chapter in answering all the questions that are at the start of the document.

1.2 The urgency of climate change action

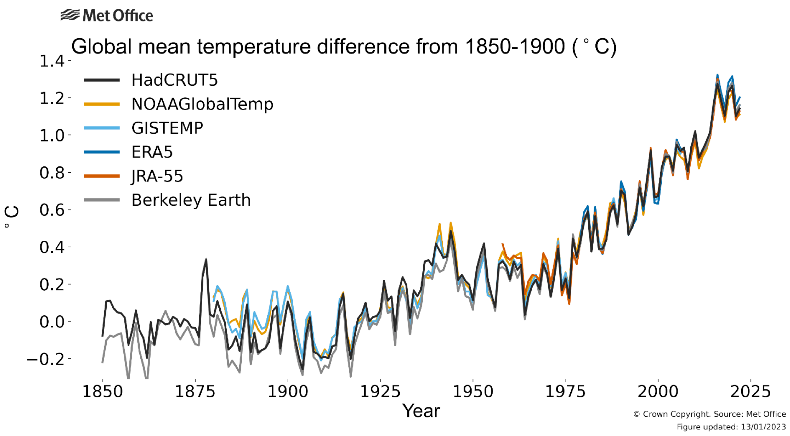
A growing share of people around the world is starting to perceive climate change as a serious matter and consider climate action to be a matter of high urgency.

A survey representing over half of the world's population has shown that almost 70% of people across about 50 countries view global warming as an emergency[1]. The survey shows wider support among small island developing states (SIDS) (74%) followed by high-income countries (72%), middle-income countries (62%), and at the end low-income countries (58%), with the sub-Saharan region being the lowest one at (61%) among regions.

Concern with climate change has spurred innovation, and increasingly motivated efforts by governments, privates, and civil society[2], which, as described by the Intergovernmental Panel on Climate Change (IPCC) in its sixth assessment report (AR6), seem insufficient to meet stated policy goals[3].

Climate change looks like the defining crisis for our times, with no corner of the world immune to its effects.

The global mean temperature for 2022 has been shown to be 1.15 ± 0.13°C above the 1850-1900 levels (Figure 1). The data-crossing among the datasets used places 2022 in the sixth position among the warmest years, marginally warmer than 2021.



Notes: The figure shows the global mean temperature differences over the years with respect to pre-industrial conditions (1850-1900) for six global temperature datasets collecting data for the period (1850-2021. World meteorological organization, Met Office Crown Copyright © (2024)

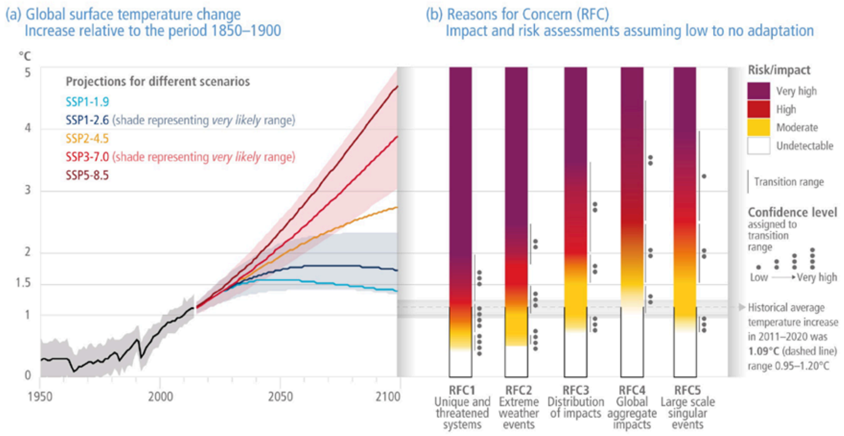
Figure 1. *Global annual mean temperature difference from pre-industrial conditions*

The 10 warmest years in the 143-year record have all occurred since 2010, with the last nine years (2014–2022) ranking as the nine warmest years on record. Of note, the year 2005, which was the first year to set a new global temperature record in the 21st century, currently ties with 2013 as the 11th-warmest year on record. The year 2010, which had surpassed 2005 at the time, now ranks as the 10th-warmest year on record.

The global average temperature has reached a point where we steadily have global averages higher than 1.0°C, which leaves only room for another 0.5°C to the target world leaders agreed to during the events of Cop21, also known under the name of the "Paris Agreement". Its overarching goal was to

[1] The G20 people's climate vote, United Nations Development programme, 2021
[2] Hale et al., 2020
[3] IPCC AR6, Section 1.1.3

hold the increase of global average temperature well below 2°C above pre-industrial records, however, in recent years climate scientists, as well as environmentalists, have been stressing the need to limit global warming to 1.5°C before the end of the century. By limiting the planet's warming to 1.5°C, wrt pre-industrial levels, by 2100, the hope is to decrease the risk of staving off severe climate disruption and tipping points that would result in harsher conditions.
The IPCC considers five broad categories of risks, denominated as "Reasons for concern" (RFCs) analyzing how these risks progressively grow with higher global surface temperatures.
It was back in 2001 when these categories were first shown, highlighting how higher levels of global temperature would lead to progressively greater risks.



Notes: The figure sums up the reason for concerns:
(a) Global surface temperature changes in °C relative to 1850-1900;
(b)The reasons for concern framework about the environmental risk for five broad categories
Intergovernmental panel of climate change, working group III, AR6, figure SPM-3

Figure 2. *Reasons for concern.*

The new assessment finds that for a given level of warming, a relatively high number of climate-related risks are higher than what was previously assessed. Compared to the fifth assessment report (AR5), there is a high confidence that the whole pack of Reasons of concern are shown to increase to high or very high-risk levels at lower temperature levels than previously thought, it is also worth mentioning that the world kept warming since the AR5 came out, therefore bringing the risks even closer.
Global warming reaching 1.5°C in the upcoming years (2021-2040) would cause severe increases in different climate hazards and create multiple risks to ecosystems and humans, near-term actions could reduce projected losses and climate-related damages in human systems and ecosystems, but cannot eliminate all of them[4].
After 2040, depending on the level of global warming, climate change will lead to numerous risks to natural and human systems. Not reaching the peak of warming will increase the chances of very high stakes for human and natural systems, the magnitude and rate of climate change and the risk associated with it depend strongly on near-term mitigation and adaptation action[5].
More climate hazards will coincide, interacting with multiple climatic and non-climatic risks, resulting in cascading risks across sectors and all global regions.

[4] IPCC WGII 16.5
[5] IPCC, WGII, 16.5

Moreover, an increase in global temperature could trigger tipping points, which occur when changes in parts of the climate system become self-perpetuating after a warming threshold.
Many tipping points might have already been trespassed[6], and many tipping systems have minimum threshold values that can be found inside the 1.0 - 1.5°C range. The possibility of triggering tipping points is already here, even with the most stringent climate mitigation of SSP1-1.9 (Figure 2), nevertheless, the achievement of the Paris Agreement's aim to limit the warming to 1.5°C would clearly be safer than keeping it under 2°C.
Current policies might not be enough to fully reach the goal imposed by the Agreement (Meinshausen, M.et al. 2022), estimating a median peak of 1.9°C, exceeding 1.5°C shortly after 2030 even under the most ambitious emission pledge scenarios.
Risks for terrestrial and wetland ecosystems are much lower limiting global warming at 1.5°C, and the difference between 1.5°C and 2°C is estimated to be huge in terms of terrestrial land affected and species endangered, as well as species loss and extinction[7].
Depending on future conditions, limiting warming to 1.5°C is estimated to reduce the range of the world's population exposed to climate-related water stress by up to 50% with respect to 2°C[8], even though we can expect considerable variability among different regions. Most global regions are projected to experience remarkable benefits from the achievement of the Agreement goal[9], although social and economic influences will have a major role relative to climate change for most communities for the upcoming 30 years.

[6] Armstrong McKay et al. 2022
[7] O. Høegh-Guldberg, et al. 2019
[8] IPCC, 2018
[9] Karnauskas, K.B. et Al. 2018

1.3 The role of methane in climate change

Methane (CH_4) has been second only to carbon dioxide in driving climate change during the industrial era[10], being the most impactful among all short-lived climate pollutants (SLCPs) for what concerns global warming, especially considering that its presence in the atmosphere has more than doubled since pre-industrial levels[11]. In order to compare the impact of different greenhouse gasses, the reports by the IPCC use an index called Global Warming Potential (GWP), a precise version of the index, GWP-100, which is the potential over a 100-year time-span, is commonly used to better compare GHGs. With the said index in fact it can express the emissions as CO_2 equivalent. The GWP measures the radioactive forcing following the emission of a certain mass of a precise substance over a defined temporal horizon, compared to the reference substance which is CO_2.

IPCC report	GWP-20		GWP-100		GWP-500	
	Non-fossil CH_4	Fossil CH_4	Non-fossil CH_4	Fossil CH_4	Non-fossil CH_4	Fossil CH_4
Second assessment report (SAR)	56		21		6,5	
Fourth assessment report (AR4)	72		25		7,6	
Fifth assessment report (AR5)	84	85	28	30	-	-
Sixth assessment report (AR6)	80,8	82,5	27,2	29,8	7,3	10

Notes: Different IPCC methane global warming potentials depending on different time horizons. International Panel for Climate Change (IPCC) global warming potential values (GWP), (07/08/24)

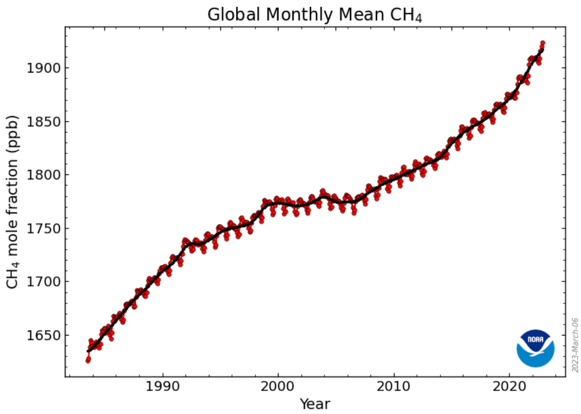
Table 1 *Methane global warming potential*

Methane lifetime in the atmosphere could be rounded up to a decade, while CO_2's presence endures from 300 up to 1.000 years, and its effects do not only limit to global warming but it contributes to the formation of tropospheric ozone (O_3) which is an SLCP as well, but it is also a dangerous air pollutant with detrimental effects to humans, ecosystem and crops.

Emissions of methane in the atmosphere are therefore a problem to human society in multiple ways, as it is not directly a pollutant and does not affect human health directly but indirectly, through climate change and ozone it does have a considerable impact.

Methane emissions contribute to global warming, damage public health, and reduce the yield of agricultural and forest ecosystems.

[10] Myhre et all, 2013
[11] Nisbet. et all, 2019



Notes: Global monthly mean of methane in the atmosphere calculated by NOAA, as part per billion over the years (1983-2021).
National oceanic and atmospheric organization, trends in atmospheric methane (2024)

Figure 3. *Global monthly methane mean .*

Amounts of methane in the atmosphere have been growing fast since the 1980s, reaching a plateau during the early 2000s, when emissions and sinks were almost balanced. In 2004 methane stocks decreased for the first and only time in the XXI century, increasing once again from 2005 onwards, rising again in the last decade reaching its highest-ever growth rate in 2021. These observations not only show how crucial is to change the direction for what regards methane emissions but also that atmospheric methane responds quickly to reductions, as shown in the plateau reached in the early 2000s.
Studies[12][13] have been discussing these trends, showing strong evidence of the fact that the increases in the abundance of methane are due to the growth of emissions globally rather than a decrease in atmospheric removal rate. Last decade's increases are shown to be caused mostly by fossil-fuel-related activities with a combined contribution of waste and agriculture.
One of the main problems when dealing with methane emissions is its identification and quantification, which are critical factors for understanding its trends and concentration.
Methane is emitted from natural and anthropogenic sources, but natural ones can be triggered by anthropogenic climate change, in which case a portion of the flux could be accounted for by anthropogenic causes. Examples are the increasing emissions from wetlands under a warming climate[14] and increased emissions due to permafrost thawing[15].
The depth of emitting sources increases the uncertainty around the estimates, and, although most sources have been identified their precise contribution to the emitting flow remains uncertain.
There are two main methods to estimate methane emissions:
- bottom-up, which traditionally uses some type of empirical data representative of the sector, multiplied by an emission factor.
- top-down which uses models and atmospheric observation to infer emissions.

Natural methane sources include wetland emissions and inland water systems, land geological sources, wild animals and insects, thawing of terrestrial and marine permafrost, and oceanic sources.
Once produced methane can reach the atmosphere in three main different ways: diffusive loss of CH_4

[12] Jackson et al. 2020
[13] Saunois et al. 2020
[14] Shindell et al. 2013
[15] Oh et al. 2020

across the air-water body, ebullition flux from sediments, or flux mediated by emergent aquatic and terrestrial plants.

Wetlands are generally described as areas where water covers soil, or is present either near or at the surface of the soil permanently or for a major amount of the time determining how the soil develops and the type of flora and fauna living in or on the soil [16]. For our aim wetlands could be described as ecosystems with inundated or saturated soil where anaerobic conditions lead to methane generation[17].

The three most influencing variables regarding methane production in wetlands are the spatial extent, temperature, and substrate availability, as well as the potential of the soil to produce anaerobic conditions for methane generation.

Wetland extent seems to be a primary contributor for what regards uncertainties in the absolute flux of methane emissions from wetlands with meteorological response as the main source of uncertainty due to seasonal and inter-annual variability that creates confusion in the estimation.

The global methane budget[18] estimates that wetland emissions represent about 30% of total methane sources, anthropogenic and natural combined, from a top-down method.

Other natural sources represent only 7% of total emissions but there are great uncertainties and lack of spatial explicit representation available to date.

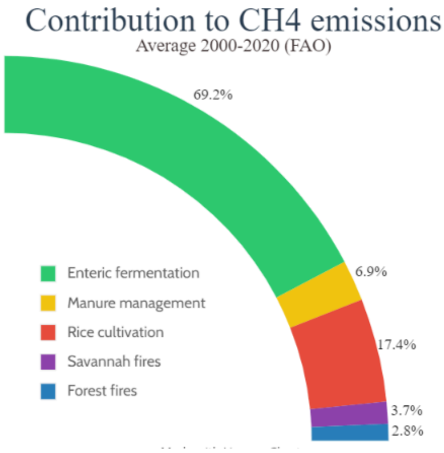
Sauonis and colleagues, also report that from the top-down point of view, the sum of all natural sources is more robust than the sum of separate wetlands and other natural sources.

Several of the natural methane sources potentially overlap with one another, especially freshwaters and wetlands. Presumably because of this, the total from adding up each individual source based on bottom-up estimates is much larger than the total value estimated using top-down methods.

Human-induced activities account for almost 60% of all methane emissions[19], and of these more than 90% are related to three main sectors[20]: fossil fuels (35%), agriculture (40%), and waste (20%).

- Agriculture: emissions from enteric fermentation and manure management make up roughly 69,2 % of total agriculture emissions, with rice cultivation rounding up to about 17,4%. Cattle are the most dominant emitters when talking about enteric fermentation while for manure management pigs are the biggest contributors.
- Fossil fuels: fossil fuel operations release methane during many processes and along the different related supply chains with a relatively fair share between natural gas operations, coal operations, and oil[21].
- Waste: landfills and waste management represent about 20% of anthropogenic methane emissions.

[16] United States Environmental Protection Agency, 2024
[17] Matthews and Fung, 1987
[18] Saunois et al., 2020
[19] Climate and Clean Air Coalition, 2024
[20] Climate and Clean Air Coalition, 2024
[21] International Energy Agency, 2021



Notes: Global contribution to methane emissions from the agricultural sector, divided by emissions sources as average of the years from 2000 to 2020.
FAOSTAT (2022)

Figure 4. *Contribution to global methane emissions from the agricultural sector.*

Livestock and rice cultivation are the main sources of agricultural methane emissions, accounting for more than 94% of total emissions.

Livestock produces methane through the digestion of feed in ruminants, i.e. enteric fermentation in cattle, sheep buffaloes, and the operation of management and storage of manure. As could be expected these values have a great variation by animal type, feed quantity and quality, and environmental context. The presence of these emissions in meat and dairy supply chains and the methane footprint of livestock is deeply connected with food security as well as cultural and behavioral patterns of food consumption. Cattle, due to their large population, size, and particular digestion, account for the majority of enteric fermentation of methane emissions from livestock[22], which become increasingly aggressive in intensive agricultural systems both in wealthier and emerging economies. Enteric fermentation methane emissions also vary from one country to another as cattle are used to different living conditions that vary spatially and temporally, especially in the tropics[23]. Manure decomposition is characterized by anaerobic conditions mainly when it is managed in its liquid form, with the volatile solids in manure producing methane.

Most of the rice is grown in flooded paddy fields and the water management systems linked to this kind of cultivation are one of the most important factors influencing methane emissions, as upland rice fields are not typically flooded and therefore are not a significant source of methane. Other factors that increase methane emissions from flooded rice cultivation include fertilization practices, soil temperature, soil type, rice variety, and cultivation practices[24][25][26][27].

In the solid waste sector, methane emissions are generated from the organic component of the waste, which in anaerobic conditions is decomposed by bacteria, producing methane that escapes into the atmosphere if not captured. Globally, around 37% of municipal solid waste is sent off in some type of landfill, 33% is openly dumped, 19% is managed through materials recovery via recycling and composting, and 11% is treated with modern incineration methods[28].

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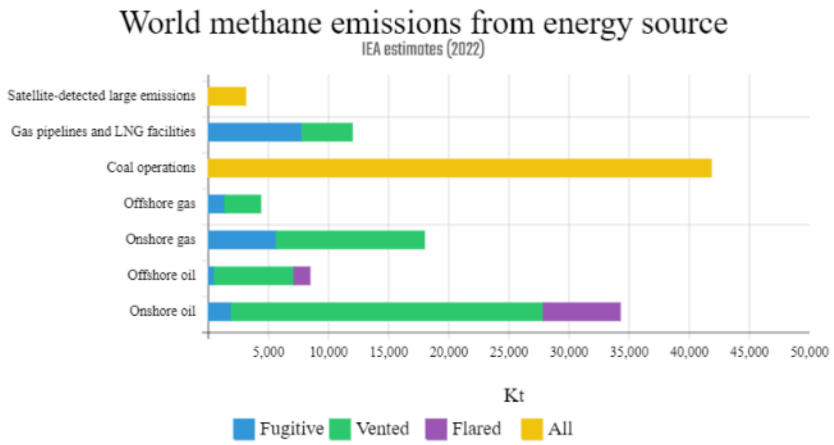
[22] Tubiello, 2019
[23] Chang et al. 2019
[24] Conrad et al. 2000
[25] Kai et al., 2011
[26] United States Environmental Protection Agency, 2021
[27] Yan et al., 2009
[28] World bank. 2018

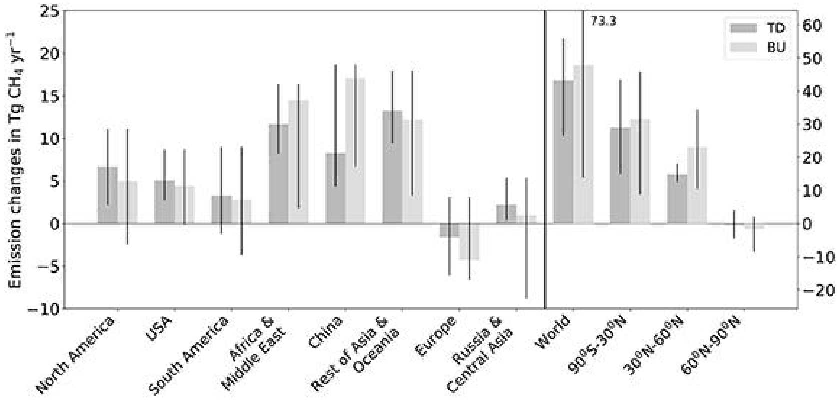
Regarding Oil & Gas, methane emissions are the consequence of the deliberate (venting or flaring) or fugitive release of methane into the atmosphere as a consequence of extraction, processing, transport, or distribution of it. Methane is often a by-product of oil and coal extraction and, if it is uneconomical to use or sell, i.e. insufficient infrastructure for transportation is burnt or directly vented into the atmosphere, as well as oil and coal processing, transport, and consumption.



Notes: The figure has been crested based on data from the International Energy agency, showing the methane emitted by every energy source.
International Energy Agency, methane tracker database (2024) reprinted with permission

Figure 5. *World methane emissions from energy sources.*

Both upstream and downstream emissions are represented in Fig. 5, with upstream emissions being related to the resource extraction gathering and processing either in onshore or offshore facilities, while downstream emissions include emissions from gas transportation and distribution by pipelines or as liquefied natural gas (LNG) and regasification.
Fugitive emissions are not intended emissions flowing through leaks, mostly with no immediate impact but difficult to detect.Vented emissions are the result of intentional releases, for safety reasons such as the design of the facility or the equipment or operational requirements, or uneconomical reasons.
Incomplete flaring CH_4 emissions may occur when methane that cannot be used or economically recovered is burned instead of gathered or vented. Most of the burning gas becomes CO_2 and water but some parts of methane cannot be combusted resulting in its release into the atmosphere.
Specific regions contributed the most to the highest methane emissions at the end of the decade relative to data gathered in the early 2000s'. Three regions, Africa and the Middle East; China; and South Asia and Oceania, have increased their emissions by more than 10 Tg CH_4 yr^{-1} assessed using both top-down and bottom-up methods. The next region with the major changes is North America, mostly coming from the United States.



Notes: Table shows the changes in total methane emissions as mean and min-max range expressed in Tg of methane yr_{-1} in 2017 values, compared with mean values from 2000-2006 period, divided by region (left panel) and latitude (right panel).

Top down values are expressed in a darker shade of grey while buttom-up values have associated a lighter shade of grey.

Figure 3, *Increasing anthropogenic methane emissions arise equally from agricultural and fossil fuel sources,* R B Jackson *et al,* 2020.

Figure 6. *Changes in total methane emissions.*

Anthropogenic sources have been estimated to have contributed to almost all the increase in methane emitted into the atmosphere in the last decade, with agriculture and waste contributing 60% of the increase and fossil fuel guilty for the remaining 40%[29].

Increased agricultural emissions were the first source in South Asia/Oceania, Africa, and South America, while the fossil fuel sector was predominant in both China and North America with the USA's fossil fuel-related methane emissions accounting for approximately 80% of the total increase from North America from 2000-2006 to 2017. A.R Stavert and colleagues[30], have found that emissions estimates for Europe are linked to a 28% decline in fossil emissions and a 17% decline in agricultural and waste emissions. Bottom-up approaches have shown that the fossil fuels decrease is driven by interventions in the coal sector (>20% since 2000) while the agricultural sector sees a decrease in livestock emissions (9% relative to 2000) and waste emissions (27% relative to 2000). Further analysis[31] provides pieces of information that show how the decrease in livestock is due to a decrease in enteric fermentation emissions and how the decrease in waste emissions is solely driven by solid waste processing.

Five regions, China, Southeast Asia, USA, South Asia, and Brazil, are responsible for more than 40% of all methane emissions during the 2008-2017 decade. The emissions are equally spread by anthropogenic and natural resources with the exception of China and South Asia where human-related emissions correspond to the ⅔ of the total. Livestock and rice are the bulk of South Asia while fossil fuel is the main source in China accounting for about 40% of its anthropogenic emissions with the remaining being equally divided between livestock, rica, and waste. Europe is the only region of the globe where methane emissions are decreasing, showing improvements from the past decade, with emissions down to negative 1.6 Tg (million tonnes) for top-down methods and negative 4.3 Tg for bottom-up methods (Fig.6).

[29] Jackson et al. 2020
[30] Stavert A. R. et al (2022)
[31] Janssens‑Maenhout et al. 2019

1.4 The case for methane emissions reduction

The short lifetime of methane, combined with the quick response of methane abundance to reduced emissions, means that any action taken to reduce the flow of emissions into the atmosphere would have an immediate positive impact on the climate, in addition to the beneficial impact it would have on current and future human health and agricultural output, studies find it technically feasible to remove 54% of CH_4 emissions by 2050 from 2015 levels[32].

Most current governmental and company-wise climate policies focus on addressing longer-term climate stability, postponing methane mitigation to midcentury due to its short lifetime. These policies further decrease methane abatement importance by using the traditional 100-year global warming potential rate of 27, undervaluing the role of methane as a short-lived climate pollutant, which increases its global warming potential to 84 when considering the 20-year GWP.

A study conducted by I.B Ocko and colleagues[33] analyzed the impact of quick methane abatement concerning delayed methane action and no methane policies.

The model presented showed an increase of 0.4℃ of the global mean average warming rate per every decade from the present to 2050 with no methane action involved with a decrease of this value of 12% when fast economically feasible actions were taken, actions that would be put in place with no net cost, or a net cost close to 0, with benefits of action that would even double if all technically feasible actions would be deployed immediately.

Quickness of methane abatement actions is also a key factor in fact a lot of targets might be missed if the actions are put in place too slowly or delayed. Both delayed and slow action would decrease the impact of such policies on the global mean average warming rate, with converging long-period results but different paths. Immediate but slow action, with full implementation only reached in 2050, would lead to an increase of almost a tenth of a degree in 2050 while delayed actions are shown to increase 0.2℃ the global mean average warming rate by 2050.

The roles of major sectors in the contribution to near and long-term climate targets from methane reduction vary and depend mostly on the sector. Economically feasible actions are open in the oil and gas sector, where 80% of the avoided methane emissions from what are considered economically feasible actions over all periods analyzed by the study.

Implementing current net zero cost mitigation measures in the supply chain of the energy sector could avoid a value around 0.1℃ of global mean warming by the half of the century with a further 0.05℃ counting also features that are not economically feasible but technically feasible.

The Global Methane Pledge has been launched to immediately act on methane emissions during COP26 catalyzing global action around the European Union and the United States. The 158, and growing, members of the pledge committed to decreasing the levels of methane emissions by 30% below 2020 levels to accelerate methane emissions curb. Joining the pledge does not represent anything binding and there are no individual targets for countries despite the request by the leading members to develop and update national methane reduction policies and plans, without specifying any action or step to take.

The group brought together many important actors both from the consumer side, such as the EU and Japan, and producers like Saudi Arabia and Iraq, but are ignored by major players like China, India, and the Russian Federation.

The number of countries that announced new policies, regulations and national commitments under the pledge is growing including numerous larger methane emitters, with the USA announcing sharp reductions of methane emissions from oil and gas operations achieving an 80% decrease in emissions

[32] Höglund-Isaksson et al. 2020
[33] Ocko, I. B. et al. 2021

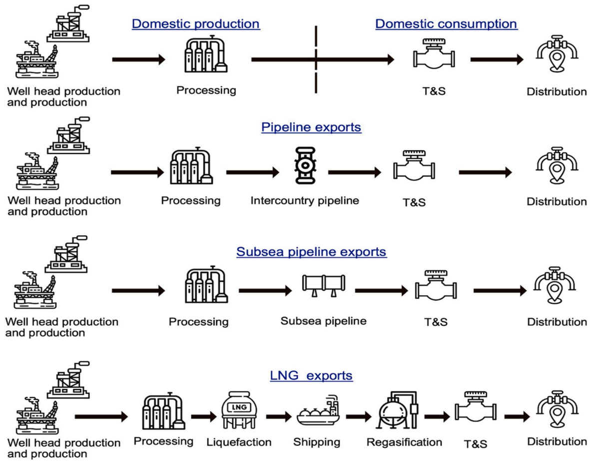
projected without such rule, while the EU is about to adopt its first methane targeted regulation increasing the strictness on reporting, monitoring, and abatement for produced, important and used oil, gas, and coal.
Canada showed an interest to achieve ambitious reduction of methane emissions in the upstream stage of the industry by at least 75% below 2021 levels by 2030 and Brazil announced to establish by the end of 2024 guidelines on methane reduction. Actions will be undertaken also in exporting countries such as Nigeria and Kazakhstan with the former showcasing major steps, including projects that will allow capturing half of all gas flaring volumes and the latter announcing cooperation with the USA to develop national standards to eliminate non-emergency venting of methane and require LDAR practices in the oil and gas sector as soon as possible before 2030.
The targets set by the Global Methane Pledge, compared to the baseline of 2030 projected methane emissions, could lead to a decrease of the already mentioned global mean warming rate of 0.22℃ over the 2040-2070 period, useful to keep the increase in global warming under 1.5℃, to 1990 levels.
Reaching such targets has been assessed to provide different societal benefits, such as preventing almost 6 (3,6-8) million deaths due to ozone exposure, as well as avoiding 580 million tons of yield losses to wheat, corn rice, and soybeans.
Methane emissions have a direct negative impact on human health due to their contribution to the formation of tropospheric ozone, a pollutant to which long-term exposure can lead to premature death due to respiratory illnesses, cardiovascular diseases, and cancer as well.
The 2022 Global methane assessment found a direct correlation between tropospheric presence and the concentration of methane as, where methane concentration increases so does ozone.
A study by Malley and colleagues[34] shows that previous estimates of the number of deaths attributable to ozone exposure were highly underestimated, and the newly estimated amount ranges from 1.04 to 1.23 million respiratory deaths observed in adults older than 30 years old.

[34] Malley, C. S. et al 2017

Chapter 2 - Natural gas supply chain and its emissions

2.1 From the wells to our house

Despite economic and policy drivers for European action against CO_2 emissions having been examined in many studies[35], literature about methane emissions is lacking. As stated in the previous chapter natural gas leaks can occur at any point during extraction, processing, transport, distribution up to and including end-use.



Notes: The figure shows the different stages of methane supply chain for different supply chains, in-land pipeline exports, submarine pipeline exports and liquified natural gas exports.
Figure 2, *The quantification of methane emissions and assessment of emission data for the largest natural gas supply chains,* 2021, Jasmin Cooper, Paul Balcombe, Adam Hawkes.

***Figure** 7. Stages of the methane supply chain*

Methane is found in different forms that can be divided into two broad groups: conventional gas and unconventional gas, while the former is composed of accessible natural gas reservoirs trapped under permeable layers of rocks the latter usually is found deeper in the earth's crust making its extraction much more difficult. Conventional gas is drilled vertically in much porous and permeable rock sediments, such as sandstone or limestone, which are drilled with much more ease. Unconventional gas, on the other hand, is linked to advancement in technology due to the deeper location and the less porosity and permeability of the rocks drilled, such as shale rocks which have to be drilled horizontally using techniques like the fracking technique, that mimics a small earthquake with high-pressure water pushed into the rock sediments creating channels that are used for the extraction of the gas, as useful as it may sound this technique does not come without problems as it can lead to a mismanagement of the water volumes and produces wastewater.
The most common method is vertical drilling, with an average depth of drill that ranges from 300 to 800 meters, limiting it to reservoirs that are not located too deep. On the other end, horizontal drilling increases the range and the possibility of reaching more reserves with fewer wells installed, but it increases the cost of the operation.
Often, natural gas is found and eventually extracted from the same fields as oil, therefore there is no search for natural gas or oil separated but single researches are set for hydrocarbons, and only after more in-depth exploration wells are drilled and it is possible to ascertain the nature of the reservoir.

[35] Le Quéré et al. 2019

The gas found on the top of oil deposits or dissolved into oil is defined as “associated gas” and “non-associated gas” when the deposit contains mostly gas, for example, the field of the North Sea or the Netherlands.

Due to the high pressure the gas is forced to, once it comes out and it has to be redirected through pipelines which have the aim to guide it it to the next process necessary to make the newly extracted gas ready to transport and use.

Generally, the processes raw natural gas has to go through before being sent to sales include different steps: at first, the gas has to be freed from condensate and water through their removal, during this first process the gas is processed in a separator vessel where free liquid water and natural gas condensate is removed and while the former is managed as wastewater the latter is sent to an oil refinery. The gas is then pressured and sent to a processing plant where the purification starts with the removal of acid gases, i.e. hydrogen sulfide, and carbon dioxide. After water vapor has been taken out of the raw gas, dehydrating the solution is followed by the removal of mercury absorbing it out of the gas.

Although not always present in the gas, nitrogen has to be removed and rejected recovering the nitrogen-enriched gas. Lastly, the gas has to be divided from other natural gas liquids via a demethanizer which results in a natural gas ready to be used for sale and different byproducts such as ethane, propane, and buthane.

Most natural gas once is set to be sold and used is transported on land with big large-diameter pipelines which operate under high pressure and are used to move gas for long distances both for in-state use and export and ends directly into processing plants, industries, or the city gates where they are connected to the distribution network. From an operational standpoint, when gas flows in the pipelines from point A to point B is due to the pressure differential existing between those two points, which is created and maintained by compressor stations located on the pipeline system network.

Such stations squeeze the natural gas pushing it at a higher pressure, allowing it to increase inside the pipeline, an action needed to keep the gas flowing.

Transport via pipeline is not the only option when it comes to natural gas transportation, liquefied natural gas is produced by cooling down the gas to a temperature of -162℃ which decreases its volume to almost 600 times granting the possibility to transport it much more efficiently, and with such flexibility that would not be possible in its gas form since pipelines have fixed routes.

Distribution is the stage of the supply chain where natural gas is delivered to end consumers, typically residents and small businesses with smaller pipelines, managed at a lower pressure level, increasing the ramification of the pipeline network to reach all different gas meters. The gas goes through city gates, where it is depressurized, measured, and odorized, if the norms say so, depending on the country. Eventually, the gas reaches its end destination, where it is depressurized once more entering the private pipeline system of end consumers through a further gas meter.

As just mentioned methane has different stages to overcome before becoming a useful energy resource, and every stage presents its different impact on the methane emissions flow:

- Production:
    - Pre-production includes reservoir exploration, site preparation, drilling, and the completion of the well, both methane and CO_2 are assumed to make a small contribution but there is not a lot of data available to underpin this assumption.
    - Exploration includes both geophysical prospecting and exploration drilling which can cause methane emissions from it. Failed explorations should also be associated with emissions.
    - Extraction emissions come from equipment leaks and vents, workovers, and liquid unloading.
- Processing:
    - The main sources of the magnitude of emissions are the fugitive and vented methane.
    - The main sources of methane emissions are liquid storage tank vents, pneumatic valve venting, and compressor and pipework flange leaks.
- Transmission and storage:
    - Emissions from the transportation and storage of natural gas come mostly from leaks from the pipeline and vented gas.
- Distribution:
    - The distribution process is the last step of the supply chain of natural gas, delivering the resource to end users via local low and medium-pressure pipelines from the redelivery point, and high-pressure transport pipelines, to houses and companies. Distribution emissions are mostly linked with pipeline leaks, vents, leaks due to corrosion of pipelines, and leaks from metering and regulating stations.

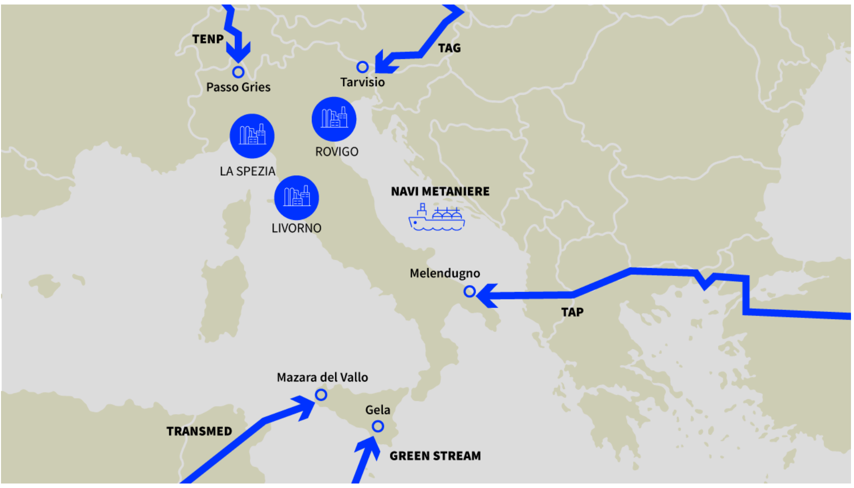
2.2 The Italian supply chain

Natural gas enters Italy's borders through twelve different entry points, both for gaseous methane and liquefied natural gas.

The main international pipelines injecting natural gas in Italy are five[36] and each of them connects the Italian transportation and storage network to a different extraction site:

- Trans Europa Naturgas Pipeline (TENP): it starts from the German-Netherlands border to the German-Swiss border carrying North Sea natural gas from the Netherlands to Italy and Switzerland. The share of natural gas injected into the Italian network was 10% of the total of natural gas imported in 2022.
- The Trans Austria Gas Pipeline(TAG): the most famous pipeline for the last year, importing Russian gas to Italy. It leads from the Slovak-Austrian border to the Austrian-Italian border, where in 2022 accounted for almost 20% of total imports.
- The Trans Adriatic Pipeline(TAP): it has been operational since 2020, and it brings natural gas extracted from Azerbaijan to Italy crossing the Adriatic Sea after Greece and Albania. It has been gaining increasing share percentages reaching 14% of share in 2022.
- The Greenstream is the pipeline connecting the Libyan extraction sites to Sicily in Gela delivering 4% of the total Italian natural gas imports.
- The Trans Mediterranean Pipeline (TRANSMED) is responsible for 33%, the most among all entry points, and connects Algeria to Italy crossing the Mediterranean Sea, as the name suggests.

All entry points connected to international pipelines are responsible for 80% of all natural gas imports in the country, another 20% is given by the regasification locations of La Spezia, Livorno, and Rovigo account for 4%, 5%, and 11% respectively of the national imports. The main exporters for NLG are Qatar, Nigeria, and the USA.



Notes: The figure shows the entrance point of natural gas in the Italian transport network, mappa del gas, *Mappa del gas, di oggi e domani,* Tirreno power, 2022.

Figure 8. *Natural gas entry point in Italy*

The shape of Italian natural gas imports has been recently changed by the invasion of Ukraine by the Russian army, leading to a decreasing volume of gas flowing through the TAG whose value decreased

[36] SNAM (2024)

by 51% from 2021 to 2022, this decrease in Russian imports led an increase in all the other import sources up to a 250% increase for the TENP volume.
Once natural gas reaches the Italian borders, it's produced or goes through a regasification plant, natural gas is moved to the distribution network, to the regional entry points, or to the biggest clients directly attached to the transportation network, such as thermal power plants or industrial producing sites. SNAM is the company managing most of the transport of natural gas (93%) and uses 13 compression plants, placed along the national network to correctly pressure the gas flow in the pipelines.
The network spreads all over Italy with a total length of more than 35.000 Km transporting about 75 billion cubic meters of natural gas, and it is divided into two parts: the national network and the regional network. The national pipeline network whose length is about 10.000 Km is made of pipelines, generally of big dimensions, to transfer gas volumes from the intaking points in the borders to the interconnection points with the regional network and the storage structures. Also, some interregional pipelines are part of it, useful to reach important consumption regions.
The regional pipeline network is composed of the rest 15.000 Km of pipelines, and it is needed to transport natural gas in delimited local areas, regionally, to supply natural gas to industrial consumers, thermal power plants, and to the distribution network.
Storage is the process that creates the possibility to store natural gas in empty deposit, and it is a needed service to optimize the use of the national pipeline network ensuring flexibility of supply-to-demand changes (economic storage) and also helps decrease problems relative to energy security, answering situations of lack or reduction of supply or possible crisis of the national network. A backup volume of gas could help in extreme climate situations or possible interruptions of supply from the pipelines (strategic storage). Italy stores natural gas in 15 different storage deposits, licensed by the government, and all storage sites are built in empty deposits. Most of the storages (65%) are managed by Stogit, a SNAM company, 20%. The storage Italian system consists of an economic storage capacity, filled during the summer season, allowing injections in the network during the winter, mostly for domestic consumption. Other than the economic storage there is a volume of strategically stored gas mainly intended as strategic stock managed only in emergencies, after long supply stops. The capacity of the strategic stock is managed by the Ministry of Environment and Energy Safety.

There are 186 total natural gas distributors in Italy, most of small or very small dimensions (74%).

Distribution operators	Number	Volume
Very big	6	17.855
Big	22	6.264
Medium	20	1.748
Small	91	2.320
Very small	47	129
Total	186	28.316

Notes: Numbers and volumes per typology of distribution operator, classified by their share in volume distributed, Arera *Relazione annuale,* 2023, reorganized with permission.

Table 2. *Distribution operators by numbers and volume.*

In 2022 the division based on the number of final clients shows 6 very big distributors (>500.000 clients), 22 big distributors (between 100.000 and 500.000 clients), 20 medium distributors (between 50.000 and 100.000 clients), 91 small distributors (between 10.000 and 50.000 clients) and 47 very small (<10.000 clients).

Distribution of natural gas in Italy happens through 269.249 Km of the network, of which in 2022, 378 were not functioning: 57,2% low pressured (up to 25bar), 42,1 medium pressured 25-64 bar) and 0,7 in high pressured pipelines (over 64 bar). In addition to the network the distribution counts of 6.881 stalls and 103.413 pressure regulating stations for the management of gas pressure along the network.

Geographically the network is spread mostly in northern Italy, where 57,5% (154.846 km) of the network, 22,8% (61.269 km) is placed in central Italy and the following 19,7% (53.134 km) is spread in south Italy and the islands.

The network of pipelines is mostly owned by distribution companies which own 81,5% of the network while municipalities only own 17,3%, the rest is owned by subjects other than the companies or municipalities.

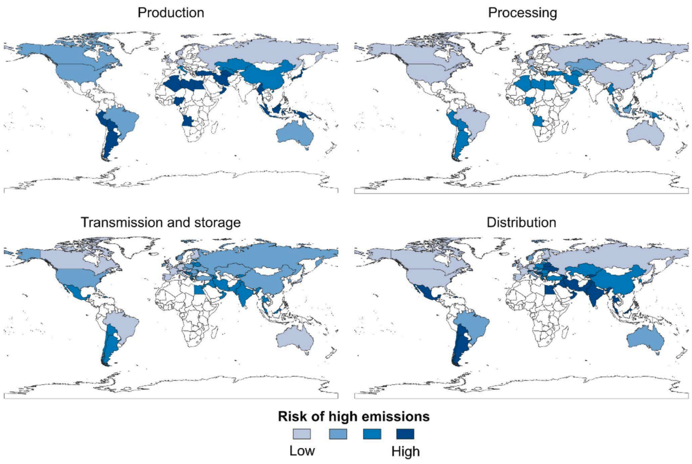
2.3 Monitoring, reporting, and verification: current practices and Italian regulation

in the boost of the understanding of natural and anthropogenic emissions. Satellite techniques can be used to detect and quantify larger leaks, enabling regional estimates of methane emissions over long periods. These technologies are not perfect and can struggle to provide reliable readings in many environments, being also impaired by weather conditions such as clouds.
The estimation of emissions is not an easy task and it differs from country to country, and emission factors for bottom-up estimate fall into one of three possible tiers, classified by the Intergovernmental Panel on Climate Change (IPCC) based on the quality of the methodology used to quantified such emissions[37].
There are three tiers:

- Tier 1- generic emission factors for developed and developing/transitioning economies;
- Tier 2- region-specific or country-specific depending on data availability;
- Tier 3- country-specific determined by experts from primary data.

The accuracy of estimates varies across the tiers, however, even within the first separation there exist large differences in measurement methods and consequent uncertainties. Tier 2 and 3 emission factors are derived from sample measurements, but the quality and the representativeness are not declared within the framework. A group of researchers[38] took a risk-based approach to assess the risk of high emissions for each region for each supply chain stage.

In this study, the risk is described as the product of a consequence and the likelihood of occurrence, with the result being the emission intensity, while the likelihood is related to the accuracy of emission reporting and quantification by each country.



Notes: Risk assessment heat maps identifying regions at risk of high emissions: production, processing, transport and storage and distribution. It is important to note that the level of risk assessed here assumes that each country is accurately reporting their methane emissions in their national inventories.
Figure 9, *The quantification of methane emissions and assessment of emission data for the largest natural gas supply chains,* 2021, Jasmin Cooper, Paul Balcombe, Adam Hawkes.

Figure 9. *Risk of emissions by country and supply chain stage.*

[37] Intergovernmental Panel of Climate Change, 2016
[38] Cooper, J. et al 2021

The results show that 58% of countries are at high risk of high emissions in production and 40% in distribution while no countries are at high risk when it comes to processing and transmission but about half are at moderate risk. This infers that many countries could be reporting their emissions in a wrong or inaccurate way. The verification of emission factors from a third-party organization is not available for the majority of countries, leading to a spread of uncertainty around the estimates.
Extraction and production of methane is a very specific stage of the chain of methane supply since not a lot of countries are net exporters and production is firmly led by a handful of regions, North America, Russia, and the Middle East, which alone extract 62,8% of total methane[39]. Methane consumption on the other hand presents a more even situation as all countries need natural gas for many different reasons. All regions present a share <25%, with North America, led by the USA, and Asia Pacific, led by China, overtaking the 20% mark. Europe, the Middle East, and the CIS find themselves all around 15%, and at the end of the pack, we find both Africa and South America with 5%[40].
Natural gas dependency on imported gas is a metric that can help to understand the idea of a heavier downstream load with respect to the less voluminous extraction industry. The European Union has a natural gas share of almost 25% in its energy mix on average and, of this percentage, more than 80% of natural gas is imported, as a result, the upstream has to face a natural gas flow 10 times smaller than the one experienced by downstream systems and networks[41]. As an example, Italy only extracts 5% of the total gas consumed within its borders, meaning that only 3.316 Mscm (million standard cubic meters) is extracted, while the Italian population consumes 68.524 Mscm[42].
In Europe, distribution is the process that contributes more to direct methane emissions into the atmosphere[43], being responsible for 59% of methane emissions estimates from natural gas operations across the EU gas supply chain for the year 2016. The natural gas distributed around the all EU has a volume way higher than the natural gas extracted or processed within the Union, as the European Union is a natural gas importer, since 2013, all 27 members of the EU have been net importers of energy sources[44]. This eventually leads to heavier emission pressure onto the downstream part of the supply chain(transport, storage, and distribution), which has to be up to the task.
Methane emissions from the distribution industry are a small share of the global methane emission flow to the atmosphere. The IEA estimates using a weighted average of different studies and databases[45,46,47,48,49,50,51], that only 2% of all global methane emissions are due to fugitive emissions from pipelines, this percentage increases if we shift the focus to Europe where fugitive emissions reach 3% of total methane emissions, due to Europe's natural gas flow in the pipelines. If we get at the national level, Italy's share of fugitive emissions reaches 5% of the whole emission estimate for the country[52].

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[39] British Petroleum, 2022
[40] British Petroleum, 2022
[41] British Petroleum, 2022
[42] Ministero dello Sviluppo Economico, 2022
[43] Gestore Italiano Energia, 2019
[44] Eurostat, 2020
[45] United Nation Framework Convention on Climate Change, 2022
[46] Crippa et al. 2022
[47] O'Rourke et al. 2021
[48] Sauonis et al. 2020
[49] International Energy Agency, 2022
[50] CAIT, 2022
[51] Food and Agriculture Organization of the United Nations, 2022
[52] International Energy Agency, 2022

The high flow of methane going through downstream processes increases the risk for fugitive emissions along both the transportation and the distribution networks. Fugitive emissions can occur for many different reasons but are mostly caused by components: valves, flanges, and connectors, which are all connecting devices part of the network. Another reason is the permeability of the different materials composing the distribution network, pressure and material lead to different emission factors, grey cast iron has the worst emission factor while steel and polyethylene are the best ones when it comes to permeability.
Due to the unwanted nature of fugitive emissions, the methodologies utilized to identify and detect these emissions vary from those that characterize venting and incomplete combustion detection, which are detected at the facility, which makes detection more complex and expensive, repairing leaks is beneficial, not only for climate purposes but also for economic and safety reasons, but the dilemma arises in the fact that gas leak detection and repair is expensive and often causes infrastructure disruption. Emissions detection can take several forms, larger leaks are typically detected using stationary leak detectors, pressure monitoring, and in some cases, personal gas monitors. For smaller leakages/fugitives, additional leak detection methods and equipment may be required and may include regular inspection rounds where hand-held detection equipment may be utilized. Leak Detection and Repair (LDAR) is a detection and management concept, that consists of monitoring plant elements, scheduling maintenance, and repairing and controlling fugitive emissions. A typical LDAR program involves the comprehensive scanning of equipment and components, from which fugitive gas emissions may occur. Individual equipment is scanned, to detect leakages at the component level, using handheld “sniffers”, soap spray, or increasingly common, Optical Gas Imaging.

The natural gas distribution industry is characterized by the presence of three main actors: policymakers, distribution companies, and end consumers, each with their aims and objectives.

Policymakers need to ensure the maximum safety for methane handling and supply, due to the high hazard posed by the inflammability of the gas.

In the last decade policymakers have been increasingly targeting the environmental impact of methane, 2012 The United Nations Environment Programme (UNEP) together with the World Meteorological Organization (WMO) partnered to create the Climate and Clean Air Coalition (CCAC) after the realization that target short-lived climate pollutants (SLCPs) would slow the rate of global warming faster than the action onto CO_2. In 2014 the CCAC launched the Oil & Gas Methane Partnership (OGMP) to create an inclusive and efficient reporting framework, which ratched up in scope and ambition in November 2020 becoming the OGMP 2.0.

2.3.1 State-of-the-art frameworks

The OGMP 2.0 provides state-of-the-art frameworks[53] when it comes to tools related to the implementation of practices for methane emissions estimation, with a reporting template that allows companies to have five different levels of reporting, from level 1, with a lower in-depth analysis to level 5 which is the most strict and reliable reporting framework.

Level 1 reporting is applicable when the company has not made any mapping of the emission sources or any survey activity and the related information is limited, for this level, emissions can be quantified using generic emissions factors. As level 1 the emissions can be reported as a unique factor for an asset or a group of assets, based on the assumptions that emissions from a certain asset might be comparable to those from a comparable asset for which more data is available.

Level 2 finds its roots in level 1 reporting and builds up adding more granularity and specifications with the creation of two differentiations between upstream and downstream processes, both further divided into fugitive, vented, or methane emissions due to incomplete combustion. Downstream fugitive emissions are additionally divided into three categories, depicting leaks from connections, tightness failure, and permeation. The emissions reported for each of the above-mentioned categories can be quantified using generic emissions factors such as level 1, even though more advanced quantification forms can be used as well.

Level 3 relies on the count of components and adds up the possibility for the company to quantify emissions using either population emission factors or leak/no-leak emission factors combined with leak detection. Component count can be made physically or using equipment-based activity factors and component-level emission factors are accepted if presented in the examples given by the OGMP or prescribed by local regulations.

The main difference arising when reporting level 3 emissions is the difference between population emission factors and leak/no-leak emissions factors, as the former takes into account an average share of components leaking and non-leaking, without particularly differentiating the two. within the population or directly average emissions from the population, also taking into account, if established, other parameters such as the percentage of methane in the mixture and the number of hours of operation. The latter instead uses two different procedures, one using the leak emission factor from a population of emitting components of the same type while the other considering that no-leak components might present a slight continuous and non detectable leaking situation which is taken into consideration in this calculation.

To classify for level 4 emission quantification measurements or specific emission factors developed based on representative measures have to be taken into consideration.

Measurements representing the total flow, or methane concentration, of each leak and surveys of the system relying on detection programs are necessary to ensure the trustworthiness of calculations. To determine fugitive emissions from unintended leaks, detecting tools with a sufficient level of performance is needed.

Level 4 emissions factors should be based on measurements conducted on representative samples for every component type, to the conditions they operate in, in order to carry a similar emission factor, while all components that do not rank as similar require a separate emissions factor based on appropriate and specific measurements studies.

To reach level 5 of quantification methodologies both source and site-level measurements are needed, reflecting the best estimates and related uncertainties for each asset. Level 5 relies also on the reconciliation between the L4 source-level measurements and the site-level measurements, which

[53] OGMP 2.0 (2024)

process should compare the sum of all assets source-level emissions made for L4 to site-level emissions which have to be taken separately from the source-level ones.
Site-level measurements allow for a top-down approach to methane emissions estimation for a specific area or group of assets and are mainly used as a check on data collected during the source-level measurements.
The following comparison between the two methodologies should highlight the discrepancies between the two approaches to derive emissions, also seen as bottom-up vs top-down emissions comparison as mentioned earlier in the document. When it so happens that the sum of source-level emissions estimates and site-level estimates appear to be inconsistent and discordant to one another, the source of the discrepancy has to be found and analyzed
L5 should include all of that, including source-level emissions inventory, measurement methods, and uncertainties as well as results if the comparison does not result in a complete reconciliation between the estimates, investigating the reasons.

2.3.2 The Italian regulation

The Italian distribution network is normed by the Autorità di Regolazione, Energia, Reti ed Ambiente (ARERA) which is helped for technical guidance by the Comitato Italiano Gas (CIG) which regulates the Leak Detection And Repair methodologies with guidelines number 7 and 16 which are constantly upgraded.
These guidelines are a technical document used as consultation and preparation for the correct use of the Delibera 569/2019/R/Gas by the Italian energy authority (ARERA), the aim is to guide the operational modalities for what regards actions not fully covered in the normative documents.
CIG guideline number 7 deals with the classification of leaks from the distribution network, and they define a unique procedure for all gas leaks and are applied to all combustible fuels.
Following this guideline's instructions all leaks have to be classified relative to their physical danger and to the risk of subsequent danger from that.
The paragraph will dive in the specifics of the guidelines to enlight the different techniques of leak prioritization and all the different aspects that derive from it.
This classification is needed to create a priority order for the elimination of the leak and the repair. The time limit depends on the danger relative to the leak, and because of the strong link between risk and priority, the operator has to keep the un-eliminated leak checked and eventually provide for the elimination once the leak gets more dangerous with time.
Prioritization will be used later in the document to estimate emissions and to develop abatement measures related to the different leak repair prioritizations.
There are four possible classes for gas leaks, in order of danger:

- **A1**: It's the leak with the most danger and it has to be eliminated before 24 hours of its discovery.
- **A2**: It's a dangerous leak, not of immediate elimination, within 7 days from the localization, but has to be kept checked.
- **B**: maximum elimination time is up to 30 days, always checked to control the situation and possible endangerment.
- **C**: the least dangerous leak, elimination within 180 days from the localization, checking it for possible deteriorations.

The distribution company has to attribute the A1 class to leaks that:

- present an immediate dangerous situation to people and/or goods.
- can be heard, smelled, or seen in a place where it could represent a danger.
- are set on fire.
- are located in cavities or buildings.

If none of these criteria are satisfied then the distribution company has to evaluate the distribution by taking into exam:

- The distance "**D"** from buildings or cavities close to the leak itself is measured in meters
- The value of the concentration gas "**X**" found inside the hole, measured as LFL, which is the lower flammable limit, the lower end of the concentration range of flammable gas, expressed in percentage by volume in the air which can ignite with air at normal temperature and pressure. Methane's LFL is 5.0 (ISO10156)

With specific reference to the distance "**D**" there can be a set of different possibilities:

1. If the leak is at a distance of less than 0,5m from buildings or cavities:
    a. If the concentration measured in the locating hole is higher or equal to 70% of LFL the leak has an A1 classification
    b. If the concentration of gas is less than 70% of LFL, control of the presence of gas in buildings or cavities close to the location hole: if presence is observed the classification is still A1, if not the leak is an A2 leak.

2. If the leak is at a distance between 0,5m and 4m from the building or cavities.
    a. If this is the case a check for gas presence in the surrounding buildings has to be made.
    b. If it is not possible to verify the presence of gas, the guideline suggests making a classification hole at a distance of 0,5m from buildings and cavities, and if the concentration of gas in the classification hole is equal to or higher than 70% of LFL the dispersion has an A1 classification, if not the classification is A2.

3. If the leak is at a distance higher than 4m
    a. If this is the case a classification hole has to be dug at 4m from buildings and if the level of concentration is less than 70% of LFL the leak has a C level.
    b. If a higher concentration is registered another classification hole of 0,5m has to be dug and if the gas concentration presence is higher than 70% of LFL the level is A2 if the concentration is lower then the classification is B

To correctly determine where the classification holes have to be made the distribution company has to virtually track the closest direct line that connects the locating hole to the buildings or the cavities closest to it. From that point on the required distances to dig the classification hole have to be calculated, which would be 4 meters and 0,5 meters.

Locating hole		**Classification hole**		**Class**
		4 metres	**0,5 metres**	
Distance "D" from buildings and/or cavities	**Concentration "X" detected**	**The presence or absence of gas**	**Concentration "$X_{0,5}$" detected**	
$D < 0,5m$	$\geq 70\% \, LFL$			A1
	$< 70\% \, LFL$			A2
$0,5m \leq D \leq 4m$			$\geq 70\% \, LFL$	A2
			$< 70\% \, LFL$	B
$D > 4m$		Presence of gas	$\geq 70\% \, LFL$	A2
			$< 70\% \, LFL$	B
			Absence	B
		Absence of gas		C

Notes: Leak relative to the distance and the concentration of natural gas in the locating and classification holes

Table 3. *Leak classification*

The only type of leak that is immediately eliminated is the A1, which as written before has to be secured in less than 24 hours, meaning that all the other leaks will be staying open for 7 days, even with a concentration of 70% of LFL.

This means that the concentration of gas that triggers major safety concerns is equal to:

$$Lim = LFL_{CH4} * 0,70 = 0,05 * 0,70 = 0,035 \quad (18)$$

So the safety LFL triggers when the volume of the body of air has a concentration of about 3,5% of methane, uncertainty is given by temperature, pressure, and the mixture of the natural gas.

The number of total emitting events can be estimated in two different ways: by in-house inspections, where the company itself provides for the inspection of the network, or by third-party warning, which is considered third-party warning every call or notification of leaking activities coming from an individual not performing planned inspections, being it a citizen or an operator on duties different from inspections.

The planned inspection aims to survey the whole network to find leaks along the pipeline system, leaks that can happen both open air and underground, ARERA forces companies to adequately inspect their network prioritizing pipelines with a higher risk of leakage:

- 3 years for the inspection of 100% of the high and medium-pressure network
- 4 years for the inspection of 100% of the low-pressure network
- 1 year for the inspection of any network not built in:
    - protected steel
    - polythene
    - restored cast iron

This is the minimum possible inspection rate for companies that can and are encouraged to increase the Km of annual inspections via an economic compensation scheme based on the constant reduction of third-party leak detections.

To calculate prices and fees related to natural gas dispersions ARERA refers to the index "number of conventional leaks detected by third party notice, for thousands of final clients" (N_{leaks}), calculated for every distribution system and every year with the formula:

$$N_{leaks} = \left(\frac{10*DT+DTA}{N}\right) * 1000 \quad (23)$$

where:

- DT is the number of underground leaks detected by third parties
- DTA is the number of aerial leaks detected by third parties
- N is the number of final clients

As we can see, every underground leak counts as 10 due to the higher complexity of their detection.

The value N_{leaks} is the foundation for the calculation of the index P_{disp} which is calculated with the formula:

$$P_{disp} = \frac{T-max\left(N_{leaks};L_{rif}\right)}{L_{Obj}} \quad (24)$$

where:

- T is the index referring to the past performances of the distribution network
- L_{rif} is an arbitrary value set by the authority equal to 3,5
- L_{obj} is an arbitrary value set by the authority equal to 7,5

The economic transfer from the regulator for every local distribution network is calculated using the following formula:

$$Inc = (P_{disp} * 0,04) * Nu * 138 * \left(1 + \varepsilon_{pc} + \varepsilon_{p}\right)^{z} \quad (25)$$

where:

- Inc is the economic transfer from the regulator
- P_{disp} is the coefficient related to the delta of leaks reported by third-party
- Q is an arbitrary value set by the authority equal to 0,04
- Nu is the total number of final clients of the distribution company
- Val is an arbitrary value set by the authority with a value of 138€
- ε_{pc} as a coefficient representing a subsidy on cathodic-protected steel pipelines
- ε_{p} as a coefficient representing a subsidy on smart monitoring for gas pressure regulation stations and it's equal to the ratio between the total number of the smart-monitored stations and the total number of stations.
- z is a weight equal to 1 in case P_{disp} is bigger or equal to 0, while it's equal to -1 if P_{disp} is a negative number.

To obtain a value for the incentive value ε_{pc} the authority calculates the ratio between the cathodic-protected steel network and the total length of the steel pipeline, the prize is given to the distribution company if the ratio reaches a certain amount, which increases yearly.

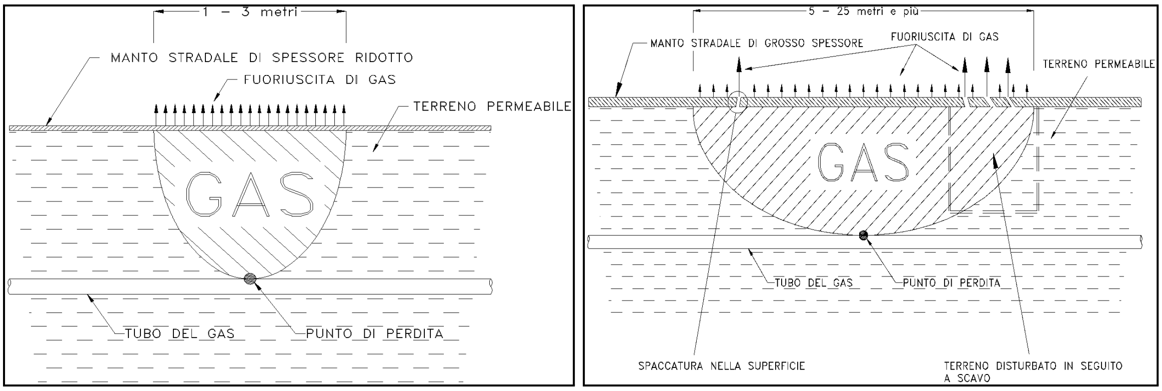
Very similar to the previous value, the estimation of ε_p is based on the ratio between smart-monitored gas pressure regulation stations and the total number of pressure regulation stations, the subsidy is given to the distribution company if the ratio surpasses 0,60, increasing up to 0,90 in 2025.
Distribution companies have duties to respect and guarantee the quality and safety of the network: granting continuity of supply, preserving the efficiency of the network, and respecting, or exceeding, minimum inspection standards, and planned inspections are performed with this perspective.
The underground pipeline is subject to various problems:

- pipeline corrosion, caused by particular acid terrain from a chemical point of view;
- pipeline break caused by pressure or land settlement;
- ruined assets on the network due to defective valves or other network components;
- breaks due to road works that moved the pipeline

The inspection activity is divided into three main segments:

- Pre-localization, where the area with the presumed leak is identified;
- Localization, the dispersion is located precisely
- Elimination, the leak is repaired, and the service is restored.

The pre-localization is probably the most time-consuming part and it is carried out both with a car equipped with a gas detector or manually detected.
The detection of a leaking activity does not immediately confirm a direct emission on the underlying terrain, due to the different behaviors natural gas has depending on the thickness of the overlaying layers.



Notes: Behaviour of natural gas leaking from underground sources, depending on the permeability of the pavement above the leaking component or pipeline.

a) Dispersion behavior with thin pavement layer (left)
b) Dispersion behavior with thick pavement layer (right)

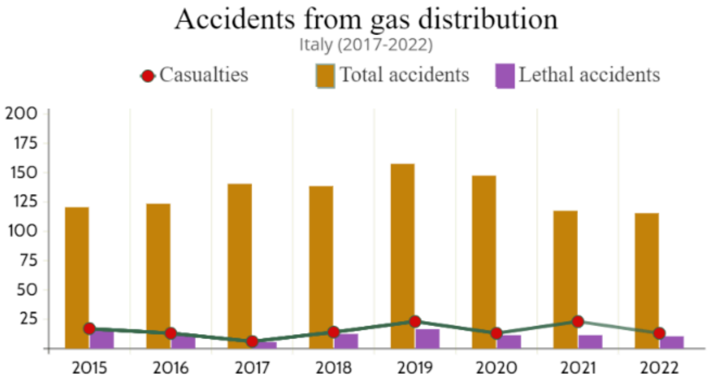
Figure 10 a - b. *The behavior of underground leaks.*

As we can see from Figure 12 the different thicknesses of the pavement layer on top of underground leaks lead the gas to different expansion. If natural gas is leaking from an underground pipeline and it encounters permeable terrain it will ascend to the ground level reaching the pavement, once there the thickness of the pavement will have a crucial role.
A thin pavement layer can grant easier access to open air while the access would be much more difficult for a dispersion happening with a thick layer. The gas once encounters the resistance of the pavement starts forming a bubble under it. The ease of gas escape is then directly proportional to the volume of the bubble, with the ease generally being directly proportional to it.

Due to this bubble effect the leak does not always show up in correspondence of the pipeline but on a way wider area, making the detection much more challenging.
Many variables can influence the surveying of the pipeline network, during the planned inspection is key to keep track of these possible conditions that might also prevent the detection from being successful or make the classification difficult.
If the surface is not permeable the gas, as mentioned before, will not be able to pass through it and will probably exit the ground from cracks, crevices, or from the sides.
When the terrain over the pipeline is made of sand or gravel, the leaked gas generally expands towards the atmosphere and will ascend in a reversed cone, and on the ground level, its area is as wide as the depth of the leak is. On the other hand, if the terrain presents cracks there could be preferential ways for the gas to exit it, taking the gas to areas far from the pipeline.
Weather conditions are also an important factor for leak detection, an iced surface is more likely to not let the gas flow through it and a wet one increases the absorbing ability of the terrain decreasing the possibility of detecting leaks. Wind speed also poses a threat to leak detection as the influence is higher as the wind speed is higher.
Leak detection has to be also performed on gas meters and aerial connections, for the former the inspections are performed during the metering of the gas meter while the latter is mainly performed during routine checks.
Arera is also working towards the decrease of the Δin-out, precisely with Deliberazione 386/2022/R/gas, a measure to hold the distribution companies responsible for the difference between the volumes of gas injected into the city gates and the volumes withdrawn by the final customers. The mechanism finds the city gates whose values of Δin-out move away from the behavior of the group of city gates they belong to and defines a penalty applied to the distribution company, which is settled depending on how much the variance is from the standard points defined by the regulator.
The regulation also presents a mechanism by which companies can get subsidies finding the illegal withdrawal of gas from the network. The distribution companies are required to undertake any action useful for the recovery of the value of the stolen gas from the subject guilty of the crime and can keep a share of the value.

Italian gas distribution companies have been found also to be inaccurate with their reporting, which is not mandatory for direct methane emissions. About 210 operators are distributing natural gas in Italy, two main operators, ITALGAS and 2iRetegas, account for about 54% of the distribution network length and 47% of the total distributed gas. Among all companies, the only one showing direct emissions from its distribution operations is ITALGAS[54], while 2iRetegas states that they are cooperating with other entities to create better accuracy for next year's report[55]. Of the companies that form the top 10 gas distributors, for the volume of gas distributed, half of the reports show methane fugitive emissions quantifying them as tons of carbon dioxide equivalent, and not always specifying the global warming potential used for the translation.

[54] Italgas, 2021
[55] 2iRetegas, 2021



Notes: Explosive accidents arising from gas distribution, related to the years between 2015 and 2022 divided in total accidents and lethal accidents in Italy, with related casualties.
Figure 2, Comitato Italiano gas, 2023

Figure 11. *Accidents from gas distribution*

The Comitato Italiano Gas statistics show how dangerous could be the incorrect use of functioning of natural gas distribution. Fig. 9 reports the accidents as well as the casualties and the lethal accidents that happened in the Italian distribution industry in the period from 2017 to 2022.

Statistically almost every year around 10% of gas distribution accidents present casualties, which can be divided into two different categories: with explosion or fire and without explosion or fire, with the latter being attributed to the consequences of the inhalation of combustion products released in the ambient due to incorrect evacuation and/or due to a lack of oxygen in the room.

The high flammability of the natural gas mixture makes distribution companies the safety guardians of the distribution service, as their first objective is to ensure that the quality and the safety of the service is ensured, as per the Italian law.

The main law relative to the safety[56] of domestic use of natural gas is n. 1083 december 6th 1971, which is still in effect , that recognized all installations and materials realized under the UNI-CIG[57] norms as complaint to the rules of good procedure for safety.
The civil code treats the matter as well, in book IV about obligations, specifically in title I: “Obligations in general”, article 1176 on qualified diligence states: “in the field of installations, professionalism is a legal obligation[58]”, and in title IX: “Unlawful acts”, article 2050 on “liability for the exercise of dangerous activities[59]” introducing the responsibilities for those performing dangerous activities, who have to prove that everything has been done on their part for the correct fulfillment of the service.
The criminal code also deals with the matter with title III about offenses, in chapter I: “completed and attempted offenses” specifically with article 40[60] “causality relationship”, that states that “failing to prevent an event that one has a legal obligation to prevent is equivalent to causing it”.
Hence the negligence on safety assurances in the distribution of natural gas is condemned by Italian law, forcing distribution companies to comply, as first obligation, to all safety procedures during the distribution activities.

[56] Specific rules of good practice, article 1: "All materials, devices, installations, and systems powered by combustible gas for domestic use and similar purposes must be made according to the specific rules of good practice, for the protection of safety."
[57]According to law 1083/71, UNI-CIG standards are the specific rules of good practice, article 3: "The materials, devices, installations, and systems powered by combustible gas for domestic use, as well as the gas odorization mentioned in the previous articles, manufactured according to the specific safety standards published by the National Unification Body (UNI) in tables under the designation UNI-CIG, are considered to comply with the rules of good practice for safety."
[58] Civil code: book IV - Obligations; Title I: obligations in general; article 1176: qualified diligence: “In the performance of obligations related to the practice of a professional activity, diligence must be assessed with regard to the nature of the activity carried out.”
[59] Civil code: book IV - Obligations; title IX: unlawful acts; article 2050: liability for the exercise of dangerous activities: “Anyone who causes harm to others in the performance of a dangerous activity, by its nature or by the nature of the means used, is liable for compensation unless they prove they have taken all appropriate measures to prevent the damage.”
[60] Criminal code: title III - The offense; chapter I: completed and attempted offenses; article 40: causality relationship:”No one can be punished for an act considered a crime by law if the harmful or dangerous event, upon which the existence of the crime depends, is not a consequence of their action or omission. Failing to prevent an event that one has a legal obligation to prevent is equivalent to causing it. An act is intentional when the individual acts with knowledge and will (envisioning and realizing the intended event). An act is negligent, or against intention, when the event, even if foreseen, is not intended by the individual and occurs due to negligence, imprudence, or incompetence, or due to failure to comply with laws, regulations, orders or rules”.

2.4 The real costs of natural gas fugitive emissions

2.4.1 Cost of methane as resource

Methane is a precious resource used both for heat and electricity purposes, and its loss during the distribution bear an real economic cost, equal to the value of the natural gas that has been emitted during the process.

Fugitive emissions are at first natural gas losses, which has well defined market price, depending on the reference market.

The Italian market of natural gas is managed by “Gestore Mercati Energetici” which manages and organizes the natural gas market (MGAS), where the operators can sell and buy natural gas.

The gas market is structured in two different moments:

- The market of the day before (MGP-GAS) takes place in two consecutive moments, the first phase is the negotiation phase where the trades are continuative while the second phase is organized as an auction. On the MPG-GAS occur trade relative to the following day to the one when the trade is happening.
- The daily market of gas (MI-GAS) where the trades happen in one session following a flowing negotiation method, where the trades are relative to the day they are happening.

The place where the trades are made is called “Punto di Scambio Virtuale” (PSV) and it is the place where offer and demand meet each other.

The price at which the gas is sold in the PSV does not reflect the price paid by end consumers in the retail market, which changes depending on the reference market. In Italy, following the liberalization of the natural gas market in 1999[61], until 2023, two markets coexisted for the consumer, the free market and the protected market. In the first one, the different natural gas vending companies offer their respective prices to the consumers who have the freedom to choose the one that suits them better, and this market is supervised by the authority together with the antitrust that ensures clear procedures and correct pricing, the latter was, on the other hand managed by the regulator projecting the prices depending on the wholesale costs of natural gas.

For the analysis the costs of natural gas has been priced at the PSV costs, reflecting the wholesale costs of natural gas for the Italian market, serving the purpose to price fugitive emissions for their real economic market values.

The PSV mean price for the year 2023[62] has been used for calculations and it is equal to 0,45 €/smc, as on the wholesale italian market natural gas has been sold for 0,45 euros for every standard cubic meter.

The index is equal to the mean of the daily quotes, expressed in €/MWh, euros per megawatt hour, and converted to euro per standard cubic meters with a coefficient 0,0105833, which is referred to the calorific potential of the gas sold in the market.

The economic values shows the actual cost that the society, in form of the selling companies, face for every standard cubic meter of natural gas that has been loss during the distribution of natural gas, later in the document the value will be helpful to estimated the economic costs and benefits of emissions and abatement measures, to develop quantitative cost-benefit analysis over the strategies proposed.

[61] Decreto legislativo n.79/99
[62] ICIS Heren, 2024

2.4.2 Cost of methane as greenhouse gas

The Italian taxation on natural gas does not take into account the environmental impact of methane in the atmosphere. A metric that can describe, giving to the direct emissions a monetary value is the social cost of methane, that would express the climate damage cost associated with an additional metric ton of methane emitted. As of now direct methane emissions are not taken into account by the price scheme and are not internalized in any framework.

The social cost is not a cost related to the volume of methane consumed but to the methane leaked into the atmosphere.

Numerous policies tackling global climate change show that carbon taxes and cap-and-trade systems are the two most important policies to reduce emissions of greenhouse gasses.

Carbon taxes have been initially proposed by Pigou[63], and are also called Pigouvian taxes, Carlton and Loury showed the inefficiency of carbon taxes in long term run and suggested a tax-subsidy scheme improving allocation efficiency (D.W. Carlton, G.C. Loury, 1980).

Adam Smith in its works praised the competitive market specifically because it is the profit the motive of innovation and not altruism that made sure that the consumers got the best bread from the collective of bakers (Smith, 1776). Similarly environmental economists like to point out that it is possible to cleaner environmental performance achievement at lower cost if general economic instruments built on market principles rather than clumsy regulation (Sterner, 2018).

Dales suggested also the concept of trade of emissions and this is becoming the crucial policy when coping with climate change (J.H. Dales, 1968), due to the benefit of affecting environmental quality directly, setting standards and limits for emissions.

The most famous example of an emission trading system (ETS) is the European Union emissions trading system (EU ETS), which covers approximately 40% of the EU's greenhouse gas emissions[64] and operates only in selected sectors (European Commission, 2022). Therefore even within the Union the system is not on full display. The number of emissions trading systems around the world is increasing as besides the EU ETS, national or subnational systems are spreading in Canada, China, Japan, New Zealand, South Korea, Switzerland and the United States.

2.4.2.1 European Union emissions trading system

A key factor that led to the creation of an emissions trading system in the European Union was the adoption of the Kyoto protocol back in 1997, which included emissions trading as one of the three so-called flexible mechanism, complemented by the Clean Developed Mechanism and Joint Implementation Mechanism (UNFCCC, 2006). Later, in 2001 the proposal for a EU ETS Directive set a decentralized approach to the matter giving to each member state significant discretion over the number of allowances allocated. A first proposal also allocated the initial allowances free of any charge for the initial trading period from 2005 to 2007 (Wråke et al., 2012).

The EU ETS works on the "cap and trade" principle, setting a cap for the total amount of GHG emitted by an installation covered by the system. The cap is constantly reduced on an annual basis and it is expressed in emission allowances, where one allowance gives the possibility to emit one ton of CO_2 or the equivalent amount of other greenhouse gasses as nitrous oxide (N_2O) and perfluorocarbons (PFCs). Within the cap companies can buy and trade their emission allowances and the declining rate of the cap ensures about the scarcity of the allowances long term giving them market value.

The annual EU ETS monitoring, reporting and verification with all its different processes is known as ETS compliance cycle. All the industrial installations and the aircraft operators under the EU ETS

[63] A.C. Pigou, 1932

[64] It covers only selected gases which, according to the European Commission (2022), can be measured, reported, and verified with a high level of accuracy.

have to present an approved monitoring plan for the monitoring and the reporting of annual emissions. The data submitted must be verified by an accredited verifier and once verified the correct number of allowances have to be surrendered. The norm dealing with compliance cycle regulation are Monitoring and Reporting regulation and Accreditation and Verification regulation.

The system, as described before was set up in 2005 and has been gradually expanded and reformed during the years, overtime in increased the intensity of the restrictions and the scope of the sectors involved. As of 2025 the system is in its fourth phase, taking place from 2021 to 2030. Phase 1 (2005-2007) was a three-year pilot project devolved from “learning by doing”, as the system only covered CO_2 emissions derived from power generators and energy-intensive industries, with most of allowances given for free to businesses (European Commission, 2022). Phase 2 (2008 - 2012) brought some reforms to the system with the aim to make it more efficient, with allowances’ number capped at 6,5% below 2005 level.

Phase 3 (2013-2020) saw the European Union take a more aggressive approach increasing the number of sectors included and a unique EU-wide cap on emissions replaced the previous national allocation plans with allowances now exchanged via auction substituting the free allocation mechanism that was previously in place. As result the price began to rise in 2017 reaching the Coronavirus crisis where prices became more volatile due to the following economic recession.

Phase 4 (2021-2030) is characterized by additional allowances cuts that pushed the price of allowances even higher at the price that we are currently experiencing today, and that will be used later in the document for estimation purposes.

The high price was argued to have effect of companies competitiveness, but several initial simulation showed only relatively modest effects on competitiveness (Bednar, 2022). Different authors concluded that the Eu ETS would not significantly effect competitiveness of companies and countries in the EU (Oberndorfer et al., 2006; Oberndorfer, & Rennings, 2007; Demailly & Quirion, 2008; Martin et al., 2014), but on the other hand studies (ITPS, 2005 or Hone, D. et al., 2006) suggested that specific sectors, such as energy-intensive industries could be face a bigger threat, showing ambiguous preliminary analysis.

As the EU ETS was further developed, more critical arguments and adverse empirical findings began rising with studies showing that is likely that companies have reacted to the EU ETS by passing-though costs to consumers (Marin et al., 2017), with studies that even clam that "The Emission Trading Scheme (ETS), …, has proved to be inefficient, especially at counteracting the effects of global trade growth." (Fanelli and Ortis, 2020). This is explained by the fact that replacing European products with emerging countries’s imports has led to a decrease in EU emissions, however this emissions did not disappear but were allocated in other countries with less stringent environmental policies.

2.4.2.2 Pricing methane

When it comes to methane emissions policies are lacking. Containing methane is a real possibility and the technological capabilities do exist, as one of the world's leading oil and gas producers, Norway, is keeping natural gas emissions extremely low. Under the current Norwegian norm regime, the practice of venting of natural gas is taxed (CO_2 tax regime), the flaring of natural gas is permitted only by the Norwegian Environmental Agency for safety purposes[65] (Petroleum Act), and the Agency also issues permits for the definition of maximum emission values at the facility level, including limits from venting and fugitive sources. Norway's greenhouse gas emissions trading Act entered into force in 2005 and the country joined the EU ETS in 2008, meaning that norwegian companies and installations in the petroleum sector as well as all other industries where ETS apply are subject to the same rules for emission trading as those inside the EU.

In order to enable a correct taxation of the resource an effective and efficient monitoring, reporting and verification program (MRV) is key, Norwegian act M-107 poses the obligation to report emissions to air, including methane emissions, as MRV is the first and most important step, providing insight, enhancing data quality and improving transparency.

Norway's action mainly focuses on upstream emissions due to the high impact that oil & gas extraction operations have on their economy.

Crude oil and natural gas amount to 73% of the total value of Norway's exports of good in 2022, with a value of about 1900 billion Nok[66].

Natural gas coming from Norwegian reserves provides 20 and 25% of the EU and UK gas demand, as Norway is the third country for natural gas exports in the world[67].

Upstream taxation is the common denominator between the different carbon mitigation policies, but the hurdle with methane emissions is that, as presented before, emissions do not only come from upstream activities, while it works differently for carbon dioxide.

In fact CO_2 emissions are taxed when generated from the combustion of fossil fuels as both taxes and allowances are imposed upstream, due to the fact that CO_2 is not a streamed resource but a by-product of energy generation and industrial production.

Methane emissions on the other hand, as mentioned before are not only a matter of upstream processes, as both transport and distribution are emitting segments of the supply chain.

During these stages gathering information on emissions as well as monitoring the leaks becomes much more difficult due to the increasing space involved in the estimation, and the decrease emissions density creates a hurdle that needs much more investments in order to be overcome.

Norway's companies are under a tax regime of 1,20 €/m^3 CH_4 for methane emissions from oil & gas activities and the combination of carbon tax and emission trading system means that companies operating on the Norwegian shelf pay approximately 131 €/tCO_2 (1500 Nok/tCO_2) for their emissions.

A recent study[68]estimates the social cost of methane (SCM), for the year 2020, ranging between 880-8100 \$/tCH_4 ,that as of October 2023 (0,95 \$/€) translates into 836-7700 €/tCH_4, with a base case estimate of 4000 \$/tCH_4 or 3800 €/tCH_4. These values correspond to 1,27-11,72 €/m^3CH_4, and the base case estimate being equal to 5,78 €/m^3 CH_4. The same paper calculates also the social cost of carbon (SCC) with the same model estimating it with a 25-1140 €/t CO_2 (27-1200 \$/t CO_2) and a base case value of 182 €/t CO_2 (192 \$/t CO_2).

The SCM over SCC ratio is a metric that could be used alternatively to the GWP and the estimates of the study report it to be around 21 while the GWP at 100 years in IPCC AR6[69] is 29,8; the difference

[65] Petroleum act, 2014
[66] Norwegian Petroleum 2023
[67] British Petroleum, 2022
[68] Azar et al, 2023
[69] Masson-Delmotte et al. 2021

is mainly due to the discount parameters used to estimate the different social costs.
The cost for a permit allowance for a ton of carbon dioxide, in the European Union emission trade system, has been valued for the sake of the document at 80 €/ton, which has been used as externality price for tons of CO_2eq by expressing the volume of methane in mass of methane, by using a density x_{ch4} of 0,796 kg/m^3[70]:

$$Q_m = Q_v * x_{ch4}$$

From the equation it can be stated that a cubic meter of methane is equal to 0,796 kilograms of methane. Then the CO_2eq mass for 0,796 kg of methane has to be calculated with the following formula:

$$Co_2eq_m = Ch_{4\,m} * Ch_{4\,GWP}$$

where the global warming potential (GWP) of methane is equal to 29,8[71].
That results in 22,91 kg of carbon dioxide equivalent at standard condition for every cubic meter of methane.
The cost for one kilogram of CO_2eq is equal to:

$$Co_2eq\ cost = \frac{EU\ ETS}{1000} = \frac{80}{1000} = 0,08€$$

hence the cost for 22,91 kg of carbon dioxide is equal to 1,83€, that by transitive property shows that:

$$1\,m^3\,Ch_4 = 0,769\,kg\,Ch_4 = 22,91\,kgCo_2eq = 1,83€$$

Hence, it is possible to estimate that every cubic meter emitted directly to the atmosphere if priced by using the EU ETS CO_2eq price has a value of 1,83€.
Cost that would be equal to 2,55 €/m^3 CH_4, using the ration SMC/SCC created by Azar et al., and 3,29 €/m^3 CH_4, with IPCC's GWP-100. These values would be both within Azar and colleague's. range for social methane cost but would be an increase of 212% and 274% respectively of Norway's tax on methane emissions.
The value of 1,83 €/m^3 of methane is the values that during the document will be used to price the environmental externalities of fugitive methane emissions, in order to develop strategies and compare the costs of abatement to the possible environmental benefits arising from it.

[70] DEFRA 2024
[71] The global warming potential of methane with respect to carbon dioxide is set to be 29,8 times by the International Panel for Climate Change 6th assessment (IPCC, global warming potential values, version 2.0, August 7th, 2024)

2.4.3 Total cost of fugitive methane emissions within the distribution network

The total cost of methane emitted in the atmosphere then would be described as the sum of its market cost (C_m) and its social cost (C_s):

$$C = C_m + C_s$$

The key factor to keep in mind is the power policymakers have on the sum, since it's within their capacity to influence and weight C_s as externality .

While in this system the first term of the equation is endogenous and it is the reflection of the equilibrium between the extraction of natural gas and its demand, the social cost it's a description of the internalization of the environmental and social effects of the presence of methane in the atmosphere. Summing the two different costs analyzed before grants a more comprehensive awareness of the real economic impact of methane and it has to be taken into account.

With such power in hands the policymaker can aim for different goals, deciding how to weight the externalities of direct methane emissions and who would bear the cost of it, the general vision would be that an increase of cost of natural gas could have different effects on the market, hence it can be used differently, with different goals in mind.

This study focuses on just the distribution of natural gas and how to efficiently account for methane emissions lacking during this precise stage of the supply chain, therefore the actors we are interested in would be gas distribution companies and consumers, understanding how they behave and how they could be affected by changes.

Targeting different actors requires different ways of reaching the goal and internalizing the emissions, when the targeted subject is a company, the goal would be to increase the cost of emitted methane, that is the methane that is emitted by the distribution company's network, such that LDAR actions become more economically feasible, by making the company pay for the volume of methane emitted. In order to achieve something like that measuring and reporting need to be up to the task steeply increasing their situation from the current state-of-the-art procedures. Such emissions would be taxed depending on the performances of the distribution company, without forcing companies or setting targets but making companies accountable for what their managed operations emit.

This methodology separates the two costs, while C_m is still paid by the consumers the correspondent C_s is on the company responsible of the emission, following what has been called as "the polluter pays" principle. This approach would increase distribution companies' costs, which could have effects onto smaller companies that have not enough personnel to carry the monitoring needed in order not to pay the tax, causing them to be swallowed by bigger companies better established in the market who can afford such costs increases, ending up threatening the existence of many small businesses in the market and competition.

Targeting the consumer instead would reconcile the two costs as the consumer now is burdened with the sum of those in its bill. The internalization here is the by-product of objectives and thresholds distribution companies have to face which costs are mirrored to end consumers as operational costs, already present in the gas bill, such cost would reflect the consumption of volume of natural gas by the end consumer. This method would increase the price the end consumer would face and, depending on the elasticity of demand and the availability of backstop technologies or substitutes for heat and electricity generation.

Understanding how the internalization works and how efficiently target it without compromising too much the markets behind it is needed to effectively tackle emissions decreasing the chances of consumer losses.

Later on this document will care to model such methodologies to understand which one can decrease emissions from the distribution and also how they affect the natural gas market from a supply or a demand perspective.

Chapter 3 - Estimating and mitigating methane emissions

3.1 State-of-the-Art frameworks and estimation techniques

3.1.1 Estimation techniques

The lack of information and on-site emission estimates create a big scissor between the possible estimated values.

The quantification of the amount of methane emitted from leaks can vary from the estimation of the emissions from a group of assets to the direct measurement based on available data, different methodologies will exhibited along this introductory paragraph[72].

The general methodology to calculate emissions is given by equation 1:

$$E = \sum_{i}^{n} E_i = \sum_{i}^{n} (EF_i * AF_i) \quad (1)$$

Where:

- **E** is the total of methane emissions in Kg
- $\mathbf{E_i}$ is the methane emission of source i
    - This could be obtained in different ways: directly measured, calculated, or estimated.
- $\mathbf{EF_i}$ Emission factor, usually expressed as a mass flow rate (Q_m) in kg per unit time and per i devices or events.
- $\mathbf{AF_i}$ Activity factor expressed as the result of the multiplication of number N of i devices or events by the duration of the leakages t_1.
- **n** is the number of all the possible emission sources.

AF_i is calculated as:

$$AF_i = N_i * t_i \quad (2)$$

Where:

- $\mathbf{N_i}$ is the number of events or devices or groups of assets. Depending on the possible category of emission they can be: the length of the pipelines, number of vents, number of leaks, or number of incidents.
- $\mathbf{t_i}$ is the duration of the leakage due to "i" event or the device, the duration is expressed in years or hours, with Q_m varying depending on the emission category.

Types of emission	EF	AF
System	Q_m in Kg/Km * Yr	N = length of pipelines in Km t = duration of the leak in Yr
Leaks due to connections	Q_m in Kg/leak * Yr	N = number of assets t = duration of the leak in Yr

Notes: Emission factors divided by type with relative emission factor measures and activity factor combination.

[72] Marcogaz, 2019

Table 4. Emission factor and activity factor

To calculate the mass flow rate from the volume flow rate we use equation (3):

$$Q_m = Q_v * x_{ch4} * \rho_{ch4} \quad (3)$$

Where:

- $\mathbf{Q_m}$ is the gas mass flow rate expressed in mass/time unit
- $\mathbf{Q_v}$ is the gas volume flow rate expressed in volume/time unit
- $\mathbf{x_{ch4}}$ methane concentration in the gas composition as a percentage (92% for Italian natural gas, ARERA 2022)
- p_{ch4} methane density (0,657 Kg/m^3)

Permeation is the gas flown through pipeline walls and it is strictly related to the material of which the pipelines are made, and used to characterize a big portion of the emission from the distribution systems, before the arrival of steel pipelines.
The general equation (4) used to estimate the permeating emission from a pipeline "i" is expressed below

$$E_i = EF_i * AF_i = Q_{mi} * l_i * t_i \quad (4)$$

Where:

- $\mathbf{Q_{mi}}$ is the emission rate in CH_4/Km every year of a pipeline. It depends on the technical features of the system.
- $\mathbf{l_i}$ is the length of the pipeline system, with the same features previously described
- $\mathbf{t_i}$ is the duration of the permeation
- **i** as the reference for a pipeline, grouping can be performed on a technical basis.

Fugitive emissions can also happen from imperfections in between connections of the different parts that compose the pipeline network: joints, flanges, valves, and other pipe equipment. Emission leaks can be then categorized and quantified via different approaches that mainly differ in precision, from an on-site one, the direct measurement to estimated ones based on surveys or the proper emission factor; a sub-categorization can also be made using the material as a filter.
Direct leak detection and measurement are performed by a single asset to determine the total emission of a group of assets measuring the emission of every single leak. This method is the best one accuracy-wise but presents the most difficulties due to the time and the expenses of the different practices of measurements and the uncertainty related to underground leaks.
The estimation calculated using the emission factor uses equation (1), with EF commonly established by results of measurements on a selected sample of assets.
Emission leaks estimated by survey give a more specific result than the EF-estimated one but it lacks the precision of the on-site calculated one, due to the nature of it.

Emission leaks which are detected during works of prevention and leak detection campaigns, are then classified as fugitive emissions and can be estimated with two different equations:

$$E = Q_m * t * n \quad (5)$$

Where:
- **E** are the emissions detected by survey in Kg/Yr
- $\mathbf{Q_m}$ average emission rate of the leaks Kg/leak*h
- **t** as the average duration of a gas leak in h
- **n** as the number of leaks detected in a year in leaks/Yr

or

$$E = Q_m * t * n * l \quad (6)$$

Where:
- **E** are the emissions detected by survey in Kg/Yr
- $\mathbf{Q_m}$ average emission rate of the leaks Kg/leak*h
- **t** as the average duration of a gas leak in h
- **n** as the number of leaks detected in a year in leaks/Km*Yr
- **l** as the length of main lines in Km

Q_m calculations and choice may differ from underground and above-ground components, as above-ground leaks are usually larger since there is no soil acting as a barrier, and the emission is not threatening if it does not reach the atmosphere.
A key parameter to develop trustworthy estimates is the duration of the leak through direct quantification attributing a time value between the emergence of the leak and its elimination. We can say that leaks randomly occur through networks and it is difficult to identify their precise timing each time one starts to emit. Different time quantification methodologies can be used to estimate the duration, which can be either backward-looking, estimating the moment when the leak started and estimating emissions since that moment, or forward-looking considering the leak rate measured during detection surveys as the basis for future emissions.
For emissions that occurred from identified leaks, following a more conservative approach, the emitting event in itself can be considered to have begun from the previous detection campaign when it remained, however undetected or from half the time in between surveys or using other leak duration estimate if it is possible to provide a methodology and a logic behind that. When a leak is detected, it is assumed to be leaking methane until it is repaired and eliminated.
Average leak duration as data is not needed when determining total emissions relying on measurement-based emission factors since the development of such emission factors, based on a leak rate, is adjusted to account for operating hours.
In this case, the duration of the leak won't impact the quantification.

The backward calculation for a natural gas leak can be determined by equation 7:

$$t = t_1 + t_2 \quad (7)$$

Where:

- **t** is the total duration of the leaks from the moment the gas starts escaping to the moment the flow is stopped
- t_1 is the duration from the start of the leak to the detection
- t_2 is the duration from the detection up to the end of the gas flow

t_1 is tricky to find since it does not usually happen to know when a gas flow starts to be poured into the atmosphere, there is an evident discrepancy between above-the-ground and underground components as with no soil acting as a barrier, as stated before, the leak is much easier to find and detect, hence the value would decrease drastically. While t_2 mostly depends on the distributor, the urgency of the repair could be determined by various factors such as the position of the leak and the intensity of the leak.

In addition to the purely fugitive emissions, leaks caused by incidents, natural or third-party caused, have to be taken into account. Those can be calculated as the results of single events, with all incidents reported and summed using equation 8:

$$E_{inc} = \sum_{i=1}^{n} Q_{mi} * t_i \quad (8)$$

Where:

- E_{inc} as the total emission from the incident in Kg
- Q_{mi} is the emission rate of the incident in Kg/h
- t_i is the duration of the incident in h

Q_m from a digging incident would be not considered as an underground leak since the pipelines damaged are not covered by soil anymore, and it has to be treated as an above-ground leak.

In the previous paragraph two different quantification methodologies have been mentioned, one regarding the use of population emission factors and the leak/no-leak emission factor, both can be used to draw estimates.

The population emission factor methodology relies on the use of a specific emission factor related to a certain type of components in its population, which can be represented by the following formula:

$$E_{type} = EF_{pop} * N_{types} * x_{ch4} * t \quad (9)$$

Where:

- E_{type} is the methane emission leak rate calculated as Kg/y for components of a certain type
- EF_{pop} as the emissions factor chosen for that specific population of components in Kg/h
- x_{ch4} methane concentration in the gas composition as a percentage (92% for Italian natural gas, ARERA 2022)
- **t** this time was used as an operational time for the unit/equipment found to be leaking

The total emissions for the population would be the result of the sum of all component types would be:

$$E_{total} = \sum_{i=type}^{n} E_{type} \quad (10)$$

Leak emission factors instead represent the average emissions from a population of certain leaking components of similar type while on the other hand no-leak emission factors consider the possibility that also non-detectable leaks might happen over such population even in small volumes.
After these assumptions, the estimates revolve around the sum of leaking and non-leaking components:

$$E_{type} = (EF_{leakers} * N_{leakers} * x_{ch4}) + (EF_{non-leakers} * N_{non-leakers} * x_{ch4}) * t$$

Where:

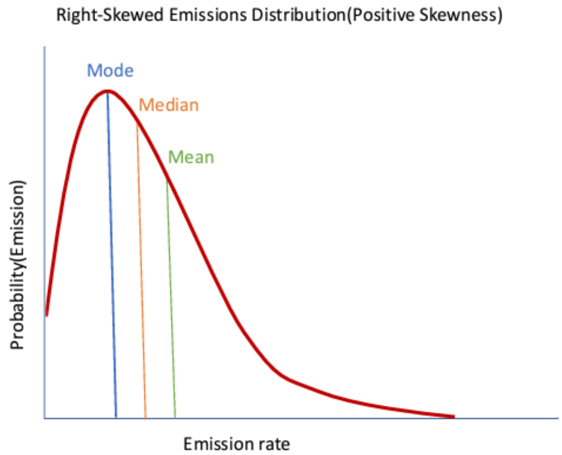
- $\mathbf{E_{type}}$ is the methane emission leak rate calculated as Kg/y for components of a certain type
- $\mathbf{EF_{pop}}$ as the emissions factor chosen for that specific population of components in Kg/h
- $\mathbf{x_{ch4}}$ methane concentration in the gas composition as a percentage (92% for Italian natural gas, ARERA 2022)
- **t** this time was used as an operational time for the unit/equipment found to be leaking

with:

$$E_{total} = \sum_{i=type}^{n} E_{type} \quad (11)$$

3.1.2 Uncertainties of estimates

The literature[73,74,75] shows how methane emissions from oil and gas infrastructure around the world tend to not follow a Gaussian distribution, presenting an inclination for both source-level and site-level emissions to follow a skewed distribution, sometimes even a so called "fat-tailed" distribution. Emissions distributions are performed through statistical sampling of a source or site-level over time, or a population of sources or sites. A normal Gaussian distribution would be represented as a symmetrical bell-curved probability distribution where mean, median and mode are all equal, while methane emissions are depicted in an asymmetrical distribution where one tail is longer than the other, with a tail "fatter" meaning that is more represented than the other in the distribution. Fat-tailed and skewed distributions are more complicated to analyze.



Notes: Overall delta in-out scheme with entrance points and exit points
Figure 3, *Reconciliation and uncertainty in methane emissions estimates,* OGMP 2.0 (2023)

Figure 12. *Generalized probability distribution*

The skewing behavior of emissions distribution has been observed both at the facility level, e.g., few emissions sources correspond to a large share of emissions, and at the source level, e.g. equipment malfunction, with a high share of emissions coming from a single source type.

The sample number required to characterize such a skewed distribution depends on the tightness of the expected distribution as well as the magnitude of the skew. When an operator does not have a lot of information about the distribution expected and emissions are material, the number of samples needs to be high to understand such distribution, using it to later inform future reduced sampling strategies.

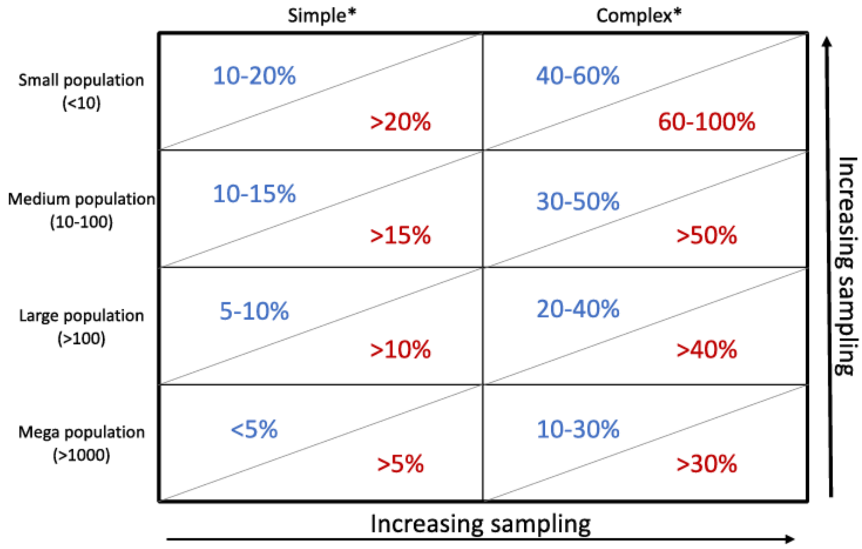
When the number of measurements is low, the risk of an outlier resulting in outsized impact increases as an estimate based on a limited sample of measurements can be biased low, since there is a statistically higher chance for them to exclude the highest emitting leaks.

The OGMP 2.0 in its technical documents provides a matrix that offers a starting point to approach sampling strategies for a population of sources and/or sites.

The first objective of operators should be to increase the robustness of efforts on reducing uncertainty around large emissions, fig 10 divides by color the contribution of a certain site/source to the asset materiality, that is the share of emissions coming out of that certain site/source with respect to the total of the asset, with the blue being low and red being high contribution. The complexity of the site adds

[73] Brandt 2016
[74] Allen 2013
[75] Ogmp 2.0, 2023

another layer of difficulty as more complex sites are expected to add variability in emissions, thus requiring a larger number of samples to sufficiently characterize the time variation in emission, with the same being applied to sources.



Notes: Starting point guidance to establish percentages of the sites/facilities/sources for sampling plans where there is a population of sites/facilities/sources.
Blue - low contribution of materiality of emissions
Red - High contribution to materiality of emissions
Matrix 1, *Reconciliation and uncertainty in methane emissions estimates,* OGMP 2.0 (2023)

Figure 13. *Sampling matrix*

Methane emission calculations carry with them a high level of uncertainty, and it is important to take it into account when estimating, it depends on the accuracy of the quantification strategy, as classified by the four possible tiers of Fig.5.
The simple approach:

$$E = \sum_{i}^{n} E_i \qquad (12)$$

paired with standard emission factors lacking measured or on-site data will provide a high uncertainty of the result, and to provide a value for the uncertainty of the estimated result, it is needed knowledge of the uncertainty of the emission factor, and the activity factor used for the calculation.
The activity factor is usually determined by a finite and known number of assets and components, which lowers the uncertainty of the value, the emission factor on the other end is usually chosen from a table of standard values or derived from emission measurements, which shares the uncertainty of the accuracy of the measurements.
The total uncertainty can be calculated using a deterministic calculation approach, as the total uncertainty U(E) could be approximated as

$$U(E) = \sqrt{\sum_{i=1}^{n} \left[AF_i * U(EF_i)\right]^2} \qquad (13)$$

Assuming a normal behavior for U and statistical independence among the different groups of assets. To estimate the uncertainty of E can be used the variance of the emission factor can imply that

$$U(EF_i) = \sigma_{EF_i} \quad (14)$$

A test can be performed, with an uncertainty of 5%, implying a value for α = 0,05,

$$\sigma_{EF_i} = \sqrt{\frac{(n-1)*S^2_{EF_1}}{\chi^2_{(n=1),(1-\alpha)}}} \quad (15)$$

Where:

- σ_{EFi} is the variance of EF_i
- α is the significance level for the test
- $\mathbf{S_{EFi}}$ as the standard deviation of the emission factor group
- χ is the Chi-squared, found on the statistical table with a value equal to n-1 degrees of freedom
- **n** is the number of measurements

While the standard deviation for the emission factor can be calculated as:

$$S^2_{EF_1} = \frac{1}{n-1}\sum_{j=1}^{n}\left(EF_{i,j} - \overline{EF_i}\right)^2 \quad (16)$$

Where:

- $\mathbf{S_{EFi}}$ as the standard deviation of the emission factor group
- $\mathbf{EF_{i,j}}$ jth individual measurement of emission factor "i"
- $\mathbf{EF_i}$ average emission factor "i"

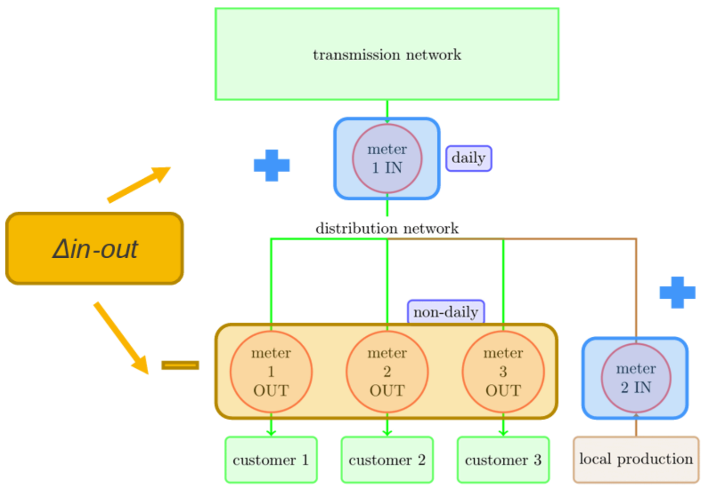
Another approach that could be used to calculate the total uncertainty of the emissions is the Monte Carlo simulation.

Greater measurements grant results when it comes to uncertainty reduction, but it bring increased costs both in terms of measurement frequency and sampling size increase. The trade-off between the deployment of resources and the possible impact of uncertainty reduction is ad-hoc, decreasing it where it matters the most when the emissions are material and the uncertainty itself is material as well. For example, decreasing the uncertainty of a source constituting 5% of 50% will not create perceivable changes in the reported emission as much as lowering the uncertainty of a source that constitutes 30% of emissions of an asset by 30%.

3.1.3 The delta in-out problem

The Delta In-Out represents a difference observed when comparing the measurements at the intake points with the sum of downstream measurements of final customers off-take points, within a certain period. The intake points where transport networks and/or other distribution networks deliver natural gas to other distribution networks are called city gates. There are also a growing number of situations where the local production of renewable gasses is injected into the distribution network.
Both local production injection and city gates are metered collecting different data regarding the intaking gas such as the gas flow, the pressure, and the temperature. Off-takes from the network are placed right before end consumers and the off-takes are measured through different meter categories which can be: daily, intraday, and non-daily metered. Distribution operators also consume natural gas to run the operating machines, from compression up to preheating of metering equipment as well as different kinds of technological consumption) and such consumption should be metered the same way as final customers are.
In a typical situation of distribution of natural gas to households and small customers, meter places in off-taking points have different features compared to intake-placed meters. There are no precise daily measurements, the only data is the volume of the gas flow with no data on pressure, air pressure temperature, and energetic measurements, and the distributing operator might have difficulties accessing the place, for example, if the meter is located in private properties, therefore the off-taking measure has a large component of estimation.
The delta in-out then is expressed by the difference between the different intake points and the total of the off-take meters:

$$\Delta in - out = Intake - Offtake \tag{17}$$



Notes: Overall delta in-out scheme with entrance points and exit points
Figure 2, *Regulatory issues related to the "Delta In-Out" in distribution networks,* Council of European energy regulators, 2023

Figure 14 *Delta in-Out scheme*

The previous equation considers the results positive when the measured intakes are bigger than the off-takes and negative in the opposite way. The time horizon when the difference is calculated is not specified and it can be calculated over any period.

There are different causes of Δin-out and many factors have to be considered, from pure network factors such as losses and fugitive emissions to measurement errors and illegal withdrawal of natural gas.

Type	Cause	Description	Impact
Losses and emissions	Vented emissions	Intentional release of gas from the network	Positive
	Accidents	Losses due to infrastructure disruptions	Positive
	Fugitive emissions	Unintentional losses from the network due to leaks	Positive
Measurements errors	Metering system errors	Measurement errors of the volumes of gas entering or leaving the network	Positive/negative
	Standard volume correction errors	Errors due to volume conversion at standard conditions and energy	Positive/negative
	Consumption estimates	Errors due to reading frequency and load profiling method	Positive/negative
Thefts and shortages	Thefts	Gas illegally withdrawn from the network either from the distribution network or bypassing or tempering the meter	Positive
	Not metered self-consumption	Not metered gas used by distribution companies for network functioning.	Positive
Delta line-pack	Previous presence of natural gas in the network	Variation in the quantity of gas contained in the pipelines of the distribution network.	Positive/negative

Notes: Type, causes, description and impacts in the Delta In-Out

Table 5. *Type and causes of Δin-out.*

Losses and emissions can be due to different causes: vented emissions are controlled emissions of natural gas to the atmosphere while fugitive ones are unwanted network losses due to operating components leaks.

Correct metering for offtakes is still an issue due to the incomplete substitution of traditional meters with smart meters, which would enable complete remote reading and standard volume correction, and the presence of natural gas from different resources with clear differences in gas composition.
Utility meters can be divided into three main categories:

- meters installed for industrial users, with technical and metrological characteristics comparable to the city gates, with a typical accuracy ranging from 0,5% to 1,0%;
- large meters, with a max flow rate >10 m^3/h, placed in large residential users, commercial sites, and/or light industries, with a typical accuracy ranging from 1,0% and 1,5%;
- small meters, max flow rate <10 m^3/h, for residential users, with an accuracy between 1,5% and 2,0%.

The meters installed in distribution networks do not enable the direct measurements of either the volumes at standard conditions or the quantities expressed as energy generated. Therefore to convert the volume of the gas flow at operating conditions into the standard conditions, due to the effects temperature and pressure have on the gas, it is needed the thermodynamic state of the gas, temperature, and pressure of the flow, as well as its composition. In Italy, standard conditions are represented by 15 °C of temperature and 1,01325 bar for what regards pressure (ARERA, 2023). Errors derived from accounting methods, as well as errors from the estimation or the processing of measurement data, generally derive from the cycle of reporting consumption and the commercial budgets related. The automatic completion of accounting is not common due to the impossibility of a complete remote reading and to the need for post-processing of consumption data, leading to different errors: inaccurate manuale reading reports, wrong estimate of non-remote users consumption through load-profiling techniques, as well as the estimation of consumption for not metered users and temporary due to breakdowns and malfunctions.
Gas theft is either illegal connections or reconnections to the distribution system by not registered end users or the bypassing or modifying of the meter to avoid totally or partially reducing the metered consumption. The estimation of theft is intrinsically uncertain, due to both the difficulty of estimating with sufficient accuracy the amount stolen and the objective difficulty of presuming the theft's existence, estimating the undetected amount possibly stolen.
The issue is strictly connected to energy poverty, which has increasingly become a very serious problem also in developed countries. Energy poverty can be defined as "a situation in which a family or an individual is unable to pay for primary energy services needed to ensure a decent standard of living, due to the combination of low income, high energy spending, and low energy efficiency in their houses"[76].
Estimating natural gas emission using the Δin-out of the network as a method is difficult due to the many different factors implied in the calculations. The accuracy of the possible emission estimation would be influenced by too many uncertainties, the system would need to be in a perfect state and almost isolated from every possible factor not being leak-related.
Solutions to reduce Δin-out percentages might help the control of emissions, such as the progressive installation of smarter meters to help increase the reliability of data coming from the extraction of gas from the distribution network as well as decreasing possible small emissions from small meters.
Another issue that needs to be addressed is the problem related to gas theft, meter tempering not only creates uncertainties in the Δin-out calculation but produces dangerous situations where standard safety measures are not guaranteed and could also create unbothered small leaks of natural gas.

[76] Osservatorio Italiano sulla Povertà Energetica, 2020

3.2 Leak detection and repair

Leak detection and repair (LDAR) programs are the tools for companies operating in the gas distribution market to keep under control leaks and avoid dangerous situations derived from the explosive hazard provided by the high inflammability of methane, and, as mentioned before in the document, only recently LDAR programs have started to be care about the environmental impact of such emissions. Periodic LDAR programs contribute to efficiently reducing methane emissions from operated assets and maximizing safety and the correct functioning of the service.

The main objective of leak detection and repair is to identify and repair possible pieces of equipment or infrastructure that can be a source of emissions. The different jurisdictions for LDAR campaigns can have specific regulatory definitions, it is usually described as the processes and systems by which leaking equipment is surveyed, identified, prioritized, and then eventually repaired. A by-product of this component survey may also be used as a tool to quantify emissions of certain types of assets.

Typically LDAR programs are developed following four different stages consisting of the preparation of the survey criteria and the components inspected in addition to the program of detection and possible quantification, followed by on-site surveys to encounter possible leaks, and if leaking components are found the repair is initiated with maintenance and the fulfillment of the reporting duties.

Leak detection and repair is one of the most important operative costs for companies operating in the distribution sector, due to the high cost of personnel required for both scheduled inspections and the repair of leaks, since both actions are very labor-intensive, as table 7 will show.

Surveying the whole network efficiently, with eyes on details needs time, and up to now, technologies rely mostly on human-driven platforms mounting gas-detecting sensors, as the company data show, to inspect the network as a matter of fact the company uses five cars mounting sensors which while driven around the area obtain informations about gas presence in such area.

Sensors should be suitable for every situation and platform, adapting for different occasions and situations, ex. walking with a carpet probe or a car driving along buried lines.

Sensor types are flame ionization, semiconductor devices, laser-based absorption, or spectroscopic, while other techniques that can also be used involve soap bubble screening and volume and pressure drop measurements.

State-of-the-art techniques also involve aerial sensors, built on drones, to decrease the level of human capital needed for the inspections, but technologies are not spread up to now, with companies preferring to stick to more traditional ways to spot leaks.

3.2.1 General procedures

LDAR campaigns require preparation to ensure efficiency and high performance, such as defining leak criteria for repair and quantification, specific threshold limit values, and the classification of the environment surrounding such leaks. The preparation includes the identification of all possible and potential emissions sources as well as the current situation of all the equipment.

Plan the whole process, comprising the schedule, resources and the organization of the on-site activities has to be carried on. The scheduling can be based on time and a fixed schedule or can be adjusted following different conditions recognizing a wider variety of asset conditions and enabling inspections's smart optimization. As of Marcogaz leaks are assessed when they exceed certain thresholds for precise values, for example, concentration or volume, with practices that can vary from country to country as well as from operator to operator, as commonly thresholds are set by local norms.

The constant need for controls over a network that can be spread for thousands of kilometers asks for a scheduling that has to cover the maximum amount of pipelines in the minimum amount of time, since the sooner the inspecting teams find a leak the lesser the amount of methane emitted by such leak, as the time of emission is one of the main inputs for the emission volume. On-the-field inspections can perceive leaks that would otherwise not be found due to many different reasons, such as corrosions of the pipeline due to chemically aggressive soil, broken pipes provoked by technical stress posed on the ground in which pipelines are set, which reasons can vary from the aboveground car traffic, settlement movements or underground human works, or as equipment losing seal strength like valves, seals or weld joints.

The areas inspected are wider than just the conduct on the maps and spread in a range along it due to the errors contained in the cartography that could make the location of the pipes not as correct as they should, beyond that the leaks, when underground, does not show itself right on the pipeline but due to the different pavement of the ground above such pipeline, the gas finds other ways to the atmosphere that could be located further away from the point of leaking.

It might happen that on the same conduct, the gas-distributing pipeline is not the only one that could create a channel for the gas to leak above the ground and whose deployment is not present in the cartography by the distributing company.

Different situations could make finding any leak difficult or completely impossible or do not allow correct prioritization with sufficient precision.

Both the morphography of the soil and the weather conditions have different impacts on the feasibility of the surveying procedures. If the soil on top of the pipeline is not permeable, such as road pavement, the gas leaked from an underground pipe would eventually exit through cracks on the surface or on the sides where joints between the road and the sidewalk are located.

This lack of permeability could create gas bubbles under the pavement, even in situations where the leak is not important in terms of volume. In the case the soil above the pipeline is sandy or grave, the gas leaked assumes a more vertical behavior as a reversed cone, whose base size, situated at ground level will depend on the depth of the leak.

Weather conditions can also affect inspections as an iced or snowy surface could prevent leaks from coming out and becoming impenetrable, while in the presence of rain or wet terrain, there could be absorbing effects that hide or minimize leaks. Wind presence could pose a hurdle for leak detection, the stronger the wind the more difficult get precise signals of gas by sensors.

3.2.2 Company procedures and tools

Within the Italian legislation distribution companies operating in Italy have certain requirements when it comes to terms related to the quality and safety of the network, such as granting the continuity of the service, keeping the distribution of the gas as efficient as possible, and following the minimum standards set by the norms for network inspections, which are stated to be, as for Delibera 569/19 issued by ARERA: 100% of high and medium pressure network every 3 years, 100% of low-pressure network every 4 years, 100% of not-compliant materials every year.
The company analyzed, on the other hand, has more stringent standards when it comes to scheduled inspection and surveying, self-posing the aim to control the whole high-pressure network every year as well as introducing the concept of endangered network, areas where leaks are more likely to be happening due to the structure of the land and the soil, as stated in their operative instructions.

Network	Italian standards	Company standards
High-pressure network	3 years	1 year
Medium pressure network	3 years	3 years
Low-pressure network	4 years	3 years
Non-compliant materials	1 year	1 year
Endangered network		1 year

Notes: Comparison between the inspections standards required by the Italian regulator and the inspection performances of the Company examined in the document.

Table 6. *Italian and Company inspection standards comparison*

Table 6 exhibits the differences between the standards currently required by the italian regulation and those followed by the company in exam.
The company covers its 14.000km, as stated by the company's data present in their website, of underground network using a fleet composed of 5 vehicles inspecting a total amount of about 8.500km every year (Inrete, 2022), divided as follows:

- 2.000km for the yearly inspected network
- 4.000km for the network to be inspected every three years.
- 2.500km extra to schedule out of mandatory inspections.

The 2.500km extra is an amount that is calculated just by subtracting the potential totality of kilometers, 8.500km, the amount of network under mandatory annual inspection, which for the company in the analysis is 6.000km. Such amount is then available for further inspections during the year, and their use is subject to an algorithm that consists of a historical-statistical analysis of the whole network, taking into account different factors developing a risk model of the different segments depending on exogenous data and the temporal factor.

The parameters taken into consideration are different and can be divided into three main categories:

- Variable characterizing the pipes and technical features:
    - Materials, pressure, and diameter
- Variables characterizing the area not depending on climate
    - Population density
    - Road pavement size
    - Land cover
- Variables characterizing the area depend on the climate
    - Weather
    - Temperature

To every analyzed segment of the network, the algorithm gives a score that is paired with the already-in-place inspection calendar adapting to it, pairing network clusters with areas already planned for inspecting, increasing the efficiency of inspection.

The vehicle has to be equipped with a system able to collect continuously a representative sample of the air layer right above the road surface and to analyze it, cruising at a speed that grants the correct sampling and analysis with trustworthy results.

Different procedures are depending on the technology used to detect leaks, which are two:

- Comb/funnel-sucking probe technology
- Carpet-sucking probe technology

For the first technology the inspection has to be carried out on the vertical axis of the pipeline or, if not possible at a distance no further than 3 meters from it, with the probes set at a 10cm height from the ground, with a maximum allowed height of 15cm.

The second technology has to be performed on the vertical axis of the pipelines as well but with a maximum distance of 2,5 meters, and with the carpet touching the ground.

When it comes to the inspection of aerial components and gas meters the procedures are slightly different, since there are no scheduled inspections for aerial components, due to the easier access and measurement, and due to the lack of norms regarding such inspections.

The company has its methodology to survey such components and the check is made by measuring the possible gas leak using the specific portable tool at a 10cm distance from the components with the highest chances of leaking, which is considered relevant with a value higher than 250 ppm.

To establish such a threshold, without any guidance from the regulator, the company decided to base the calculation on the maximum allowed gas concentration inside the average gas meter, which is equal to the allowed leaks by the most common components.

The leak detection activities on aerial components or gas meters can be performed by operators during specific activities with that specific aim, during gas meter reads, activation or disabling of a customer gas supply, or, gas meter substitution.

When the pre-localization is made thanks to portable equipment the operators that are responsible for the inspection proceed, where possible, on the vertical axis of the pipeline with an allowed maximum distance of 1,5m from it. Whenever the lower limit of the equipment is exceeded the operator should carry on with the localization procedures.

The localization of the leaks has to be performed as soon as possible, and at least before the maximum time of 30 days from the pre-localization. Priority criteria for the localization take into account different parameters:

- The pressure of the pipeline
- Measured value during the pre-localizations
- Distance from buildings
- Distance from dangerous tunnels or cavities
- Population density of the area
- Road pavement

For leaks from aerial components and gas meters, the operators responsible for the intervention have to take action in the 24 hours following the pre-localization.

3.2.3 Leaks located during inspections

Before localizing a leak with precision, the first step of pre-localization is performed. The first procedure that takes place is the study and analysis of the pipeline mapping for the interested area, helped by both cartography and pipeline localizing tools.

Pre-localization is usually performed right above the crown of the pipe or as close as possible to it, and it is needed to understand from which exact point the gas leaks above the ground. As mentioned before when the soil above such a pipeline is a hermetic pavement the pre-localization has to be performed by inspecting all possible exit points for the gas, such as sidewalks, manholes, or any other joint that might create easy access for the gas leaking underground to disperse in the atmosphere.

Once the leak has been pre-localized, the operator shares the location with the colleagues in charge of the localization which gets to the location and starts the real localization processes.

They make a series of holes with the same depth, located on the crown of the pipeline close to where the leak has been pre-located with enough depth to reach the soil under the pavement.

Once the holes are drilled the sensor is placed inside to measure the gas concentration, report the concentration, and proceed with the classification of the leak.

3.2.4 Third-party notified leaks

operator during any activity by not being inspected have to be counted as a "third-party notified leak". Such lettering is included also all leaks detected by customers and citizens through the odorization of gas, this method is key to preventing any dangerous situations in areas where inspections have not been carried out recently or in possibly critical areas, such as residential areas.

This prosumeristic approach increases the possibility of leak detection on the most dangerous part of the network, decreasing the chances of harmful accidents due to gas leaks.

Gas odorization is a key aspect in the efficiency of gas detection when there are no tools or sensors, with that all leaks are detectable if the concentration of gas becomes inflammable.

Distribution companies have to perform mandatory inspections of the odorant concentration every year to ensure the correct odorization of the gas distributed, as the odorization of the gas is the responsibility of the distributor managing the pipeline where that gas is flowing.

When a leak is detected the consumer, the company operator, or a third party operator, has to call the company number to notify a possible leak, the number has to be reserved for emergencies and calls have to be answered in a maximum of 120 seconds, with a 10% of possible calls not answered on time every year.

Once the company gets the notification a team of operators has to show the area of the possible leak before 60 minutes, as stated by the regulator in the above-mentioned norm, and proceed with the elimination according to the norms about leak elimination. The minimum percentage of calls with a team showing up on time is 90%, as stated by ARERA, under such timing the company fall afoul of sanctions.
As mentioned in the previous chapter third-party notified leaks are a key component for the economic subsidies given to gas distribution companies, as despite their importance they enlight a breach into the inspection procedures, which is more like a systematic breach due to the difficulty of constant control of pipelines.
The regulator rewards companies that can decrease the number of leaks detected this way, through the economic incentives ruled by the scheme expressed by equation (25) which becomes equation (27) if it is considered the whole company's distribution network, as it is considered withing the rules expressed in Delibera 569/19:

$$\sum_i^n T_i = \sum_i^n Inc = (P_{disp} * 0,04) * Nu * 138 * \left(1 + \varepsilon_{pc} + \varepsilon_p\right)^z$$

which awards companies decreasing the number of third party notified leaks for thousand consumers regulated by art. 42, 43 and 45 of such delibera, in actual fact increasing their efforts on inspection campaigns with the specific aim of decreasing the chances of unseen leaks and creating profitable investments in leak detection and repair procedures.
Article 42 in addition expresses the possibility for distribution companies to lose the right to all possible positive economic transfers for a network with the presence of explosive incidents in such area, proven that such explosion were not due to extenuating circumstances or caused by third parties.
Up to 2024 the years that have been evaluated for the economic transfers are until 2020, and for the years 2018[77], 2019[78] and 2020[79] the Company examined scores a positive economic transfer for the whole period:

Year	Economic trasfer
2018	€ 1.533.358,84
2019	€ 2.505.513,54
2020	€ 1.752.243,28

Notes: The table shows the economic transfer, expressed in Euros, which the Company examined in the document has been awarded for the years 2018-2020 by the regulator, due to the economic transfer method based on the performances scored in leaks notified by third parties Database ARERA (2024)

***Table** 7 Regulator economic transfer*

The yearly economic transfer is the sum of all economic scores for all networks, as every network is valued separately and the result given by expression (25), which can be positive or negative depending on the company performances on such network, is used to develop a comprehensive economic transfer which takes into account positive and negative economic scores for all companies.

[77] Arera, 2021
[78] Arera, 2023
[79] Arera, 2024

3.3 Leak detection and repair costs

As mentioned before leak detection and repair is beneficial, not only when it comes to environmental externalities but also for safety reasons and economic causes. The dilemma on the financing of such campaigns by distribution companies arises in the fact that there are costs associated with leak detection and repair and work on the pipeline can result in disruption for public infrastructure when the leak is detected underground.

Since LDAR procedures help avoid emissions, hence losses in natural gas the costs associated with them have to take into account the volume of methane that is not yet got into the atmosphere, which makes up for some of the costs of the containing procedures.

Leak detection and repair have different costs, which can be divided first into two different categories:

- Inspection costs
- Leak elimination costs

Both of them deal mostly with personnel costs, but while the former is composed of planned costs and fixed ones, fleet, planned inspections, and equipment, the latter is an opex cost as the company does not know what leak will be found, how deep they will be in the soil and how long it takes for the operator to eliminate the problem.

Inspection costs are consistently lower than elimination costs due to the magnitude of operators involved, as the operators needed for inspections are just those who are part of the fleet inspecting pipelines while leak repair engages a bigger amount of operators, in much more time-consuming operations.

3.3.1 Inspection costs

As mentioned before, inspection costs have mainly a capex structure due to the fixed costs of the fleet, their consumption, and maintenance, which is mostly planned, and the given set of kilometers such fleet has travel.

Personnel costs are the only cost billed by the company as pure inspection costs while costs for the fleet are not shown by the company as inspection costs but it can be added that, at least, gas costs are as well costs derived by the inspections, and could be estimated by the km inspected every year.

Extra costs that could be added to gas costs are the ones related to the kilometers traveled to get to the starting point of the inspections from the fleet garage.

As highlighted inspection costs can be divided into two main sides, fleet costs that are dependent on the kilometers traveled by the vehicles part of the fleet, which is a negligible cost, and a major other component in personnel costs, which on the other hand are dependent on the hours spent inspecting by the operators.

While the former is mostly fixed, as the company knows in advance how many Km of pipelines they plan to inspect, the latter is more dependent on the number of leaks found during the inspection, which increases the time needed for the operations.

The more leaks are found by the inspecting operators the more time is spent pre-localizing them and eventually localizing them with precision.

In the past years, the company was able to increase the efficiency of inspection procedures, going from a rate of 0,69 kilometers inspected every hour to a rate of 1 km/h in 2022, this decreases the costs for inspections, as the cost for inspection a km of pipeline decreases by more than 30% from 55€ km/inspected to 37€ km/inspected, company data shows that the hourly cost for personnel expenses for any operator busy with leak inspection. A linear increase in efficiency is also reflected in the decrease of the full-time equivalent for personnel work, which expresses the number of full-time personnel employed in leak detection.

This increase in efficiency gives the company the possibility to increase the possible range of covered kilometers without increasing the budget due to the cause.

	Personnel costs	Work Hours	Full time equivalent	Hourly cost	Per Km inspected	Per leak found	Fleet costs
2022	329.503,97 €	8.863,00	5,3	37,18 €	€ 37,25	€ 312,960	€ 4.226,43
2021	417.124,87 €	11.195,00	6,7	37,26 €	€ 49,97	€ 232,257	€ 4.193,44
2020	376.973,31 €	10.014,00	6,0	37,64 €	€ 47,92	€ 219,681	€ 4.107,09
2019	429.211,81 €	11.337,00	6,8	37,86 €	€ 56,55	€ 201,998	€ 4.395,66
2018	445.654,53 €	11.537,00	6,9	38,63 €	€ 58,36	€ 201,408	€ 4.702,32

Notes: Cost for personnel dedicated in inspection procedures for the years examined in the document, 2018-2022, showing different indicators: worked hours, full time equivalent of working hours, hourly costs, personnel cost per kilometer inspected, personnel costs per leak found and fleet costs.
Company dataset, *Dati economici emissioni metano*; *RFP* (2023)

Table 8 *Leak detection personnel costs*

Tab. 8 shows how the costs for personnel over the years, displaying a overall decrease in costs as the time went on, while the amount of leaks does not have such trend and the kilometers inspected on the other hand increase over the years, exhibiting an increase in efficiency for what regards inspecting operations.
The personnel costs reflect costs related to the costs of operators fully focuses on the inspections of the network, and the second column refers to the hours worked by such personnel over the year, followed by the full time equivalent which is the numbers of people considered working full time on such task.
The following columns analyze different aspects such as the cost for every hour spent inspected or for every kilometer inspected by the operator, as well as the cost per every leak found during such operations, while the last columns focuses on the costs for the fleet maintenance.
Increasing detecting operations as kilometers surveyed, via major efficiency or increasing the investments towards it, helps with decreasing the number of leaks found during every inspection, due to the less time passing in between inspections, this would eventually translate in a decrease of the time spent during leak detection surveys, due to less leak detecting stops, hence, increasing the efficiency of the procedure. In addition, it would also create environmental benefits due to leaks being detected earlier than what they would with a less stringent inspection schedule, releasing less methane in the atmosphere.

3.3.2 Leak repair costs

Once a leak is detected and located, not only via leak detection surveys but also through third-party notification, company operators then proceed with its elimination.

All leaks when detected have to be classified, into four classes: A1, A2, B, and C, following a scheme that gives the most dangerous leaks the higher priority, then leaks that are dangerous when detected would have a class A1 rank while leaks that do not prove any risk for harm would be classified as C.

Different classes have different priorities, while A1 leaks have a maximum elimination time of 24 hours, such limit increases with the decreasing of priority, as A2 leaks can be eliminated in a week, B in a month and C-type leaks can be opened up to 180 days.

Leak prioritization has an impact on costs mainly due to the possibility of leak elimination scheduling, as different leaks have different elimination timing is possible to spread the amount of leaks to eliminate along the allowed period, decreasing the organizational pressure onto the operators.

Without such different scheduling, there would be an increase in the need for personnel as all leaks would need to be eliminated in a shorter amount of time, hence increasing the personnel cost for leak elimination.

The composition of leak elimination costs is much more complex than what it is for the cost of detecting leaks, as the voice costs are higher and the overall time and operational costs are higher.

The cost analysis for what regards the intervention and the elimination of leaks shows how the majority of the budget is spent on personnel expenses, due to the high number of operators needed for the task.

There are three main categories of invoices for what regards leak elimination costs:

- Personnel
- Fleet
- Materials
- Services
- Management

Personnel expenses cover steadily about 60% of total leak elimination costs during the time going from 2017 to 2022 every year making it the first invoice costs, at the second step services costs make up for an average ratio of 30% of the total costs, mostly due to maintenance interventions and services. Fleet and materials do have not the biggest impact on the costs as combined they are around 10%, with materials having a little edge over the tool costs.

Management has a risible impact as costs for such operations don’t exceed 0,3% and are often negative, due to positive economic transfers accounted to this invoice.

Cost invoice	2022	2021	2020	2019	2018	2018-2022
Fleet	250.687,97 €	162.503,94 €	174.864,70 €	215.243,82 €	233.189,46 €	1.036.489,89 €
Materials	401.187,84 €	398.894,39 €	248.124,45 €	287.496,52 €	258.158,67 €	1.593.861,87 €
Services	1.526.686,88 €	1.365.362,62 €	1.659.175,89 €	2.075.494,88 €	1.772.331,39 €	8.399.051,66 €
Management	2.486,00 €	12.274,54 €	- 17.683,09 €	- 115.572,41 €	3.375,60 €	- 115.119,36 €
Personnel	3.417.749,16 €	3.117.857,37 €	2.722.830,61 €	3.216.955,59 €	3.665.542,07 €	16.140.934,80 €
Total	5.598.797,85 €	5.056.892,86 €	4.787.312,56 €	5.679.618,40 €	5.932.597,19 €	27.055.218,86 €

Notes: Different cost invoices for leak elimination procedures, for every year examined in the document, from 2018 to 2022.

Company dataset, *Dati economici emissioni metano*; *Pronto intervento* (2023)

Table 9 *Cost invoice for leak elimination expenses*

In detail, personnel costs deal with just the hours worked by the operators in charge of the elimination of leaks.
As mentioned before services are mostly composed of costs of maintenance but also by consultancy needed for efficient elimination, while costs related to the fleet are only related to the costs of fleet movement and maintenance.
Since personnel costs are the wide majority of costs of elimination of gas leaks along the network, as it happened with inspection costs, it is possible to state that leak elimination is a labor-intensive operation.
Costs in the elimination of leaks can increase in two main ways, both related to the increase in operational stress, which can be explained by the number of operators requested to perform leak elimination at the same moment in different positions, hence increasing the number of personnel requested, meaning the need for further personnel hiring, and, consequently, costs.
Operational stress can be reached with an overall increase of leaks, for example by the increase in the range of the network to cover with leak elimination or with a decrease of the threshold which defines a leak as a leak to eliminate. These two possibilities increase the overall stress on all four classes, presumably, in the same ratio to all of them, with the main issue being the increase of leaks that need immediate elimination, hence not permitting any scheduling.
Operational stress can also increase by decreasing the elimination time in which leaks have to be eliminated, assuming that the number of leaks remains the same. This would increase the stress because many more leaks would have to be eliminated in a shorter amount of time, hence increasing the number of personnel requested for such operations. For example, an increase of leaks to eliminate during the following 24 hours after the localization would increase the need for personnel due to the increased chances of a high number of leak elimination procedures performed at the same time.
Keeping the number of leaks constant while increasing the priority of elimination could have impacts not only on the personnel costs due to the above-mentioned organizational stress but also on fleet costs due to the finite number of vehicles used for leak elimination procedures that have to increase as a consequence of organizational pressure.
Other costs won’t be increasing due to the number of overall leaks not increasing, as all other costs are not influenced by the increase of higher prioritized leaks but more by the overall increase of leak volumes.

3.4 Company-level case study

The study of the data gathered with the cooperation of the company we are taking into exam resulted in an estimation of methane emissions helpful to understand the impact of both environmental externalities of methane emissions and the economic losses related to the natural gas loss.
The company performance analysis is composed by two different estimations differing one another by the methodology used to estimate the amount of methane leaked from the distribution network of the company taken into consideration and depends on different levels of analysis.
The first estimation provided in this chapter will be dealing with the generic emission factors of pipeline materials since every material and pipeline has a different estimated amount of methane emitted for every kilometer of network deployed.
The second analysis is split into two different analysis, the first focussing on the time pre-localization of the leak, related to the incubation time, which in the document is assessed to be the time the company does not know the leaks existed, starting with the leak appearance and ending with the localization of the leak, while the second part will be focussing on the post-localization existence of the leak, related to the elimination time, expressing the time the company knows about the fugitive emissions and any delay on its elimination is related to informed choices of the distribution operators.
This analysis has the goal to show how the data gathered have been used and what insights come out of the results.
The main issue with emission estimation is the lack of emissions factors, due to the non-existent reporting regarding the flow of emissions out of leaks, which is based on estimates.
The lack of precise emission factors, or source-based emission factors, does not allow us to grant to every leak, or at least every leak from different sources and source-based emission factors.
Due to that, all leaks have the same emission factor, which is naturally not perfect as dimensions and pressure differ from one source to another.
The lack of reporting information is the first insight that we can assess once analyzing the data gathered as well as the literature, as no study has been made following reliable survey data and only a few technical guidance documents can rely on some sort of source-level data.
An increase in reporting will enable a major development for abatement analysis as well as increasing and developing the possibilities for action where the leaks are found to be emitting above the average, possibly enhancing the creation of priority classes dependent on such factor.
The lack of reporting gives to the analysis a generous dose of uncertainty which will follow all estimations, the more the lack of data is important the more uncertainty the analysis faces.
Uncertainty mostly is related to two data, time and the rate of emissions, expressed by the emission factor.
In addition to the study and the estimation of the company performances, such performances have been compared with the maximum estimated emissions allowed by the current Italian regulation.
In order to do so, at first the maximum allowed estimation have been estimate using as data for the estimation the minimum network inspection frequency required by the regulator, and the maximum time allowed for leak elimination allowed by the different priority classes.
Such values as it will furtherly explained in the document substitute respectively the latency time and the scheduling time and are used as indicators for regulation performances.
The comparison then is given by examining the difference between the two estimation in order to have an idea of how much Company performances distance from the maximum performances allowed, giving a broad picture of the lacks of stringency of the current regulation where the distance is higher.

3.4.1 Generic emission estimation

The emission factor that used for this first analysis is the one published by the Istituto Superiore per la Protezione e Ricerca Ambientale (ISPRA) within the greenhouse gas inventory published in 2024 and related to the data of 2023, which gathers different data regarding all companies and sectors responsible for greenhouse gas emissions, although some lack due to the methodology of data gathering which is voluntary, crossing such data with technical work made by ISPRA over the years.
The two main factors regarding the generic emission factor by ISPRA are the materials of the network and the pressure at which the gas is distributed.
The emission factor, in this case, measures the standard cubic meters (scm) of natural gas leaked for every Km of network of a specific materials, such emissions factor are further divided in medium pressure (MP) with an operating pressure lower than 5 bar and higher than 0,04 bars and low pressure (LP) with an operating pressure lower than 0,04 bars.The analysis does not account high pressured network since distribution companies mainly deliver the gas through network under 5 bars.

Emission factor ISPRA 2023 (scm/km)					
Steel		Polyethylene		Cast iron	
MP	LP	MP	LP	MP	LP
319,90	207,50	189,90	189,90	391,00	328,30

Notes: The emissions factor are estimated by Ispra and are expressed in standard cubic meters of natural gas emitted every km of network, "Leakage emission factors of natural gas for transmission and distribution in pipelines by material and pressure (2022)".*National Inventory Report*,(2024)

Table 10. *Emission factors for different network materials*

The network analyzed is composed of pipelines made with different materials, that have to be analyzed singularly. There are three main materials used, which are steel, polyethylene, and cast iron, with the last one being slowly replaced with the most efficient pipelines due to its high emission factor and the lower safety level concerning steel and polyethylene.
The network length[80] here is the activity factor, the factor used to quantify the emissions through the emission factor. It can be seen that the total amount of the network increases over time because of new acquisitions, but as the total Km increases the kilometers of cast iron pipelines decrease, due to current norms to renew the network, willing to fully deploy only pipelines made of steel.

Network length (km)	Steel		Polyethylene		Cast iron	
Year	MP	LP	MP	LP	MP	LP
2018	7.847,25	4.039,11	814,72	361,78	0,00	745,74
2019	7.854,82	4.040,68	817,16	369,32	0,00	738,28
2020	8.115,51	4.329,32	843,80	390,18	0,00	729,36
2021	8.120,33	4.332,61	844,09	412,49	0,00	721,84
2022	8.117,62	4.336,73	845,26	444,04	0,00	715,23

Notes: Network length is calculated from Company data for every year that is taken into account for the document, divided by the material of the network and the year.
Company dataset, *Dati tecnici; 5-6 consistenza rete* (2023)

[80] Annex II.I - Table XVII

Table 11. Network length

To estimate the emissions equation (1) can be used:

$$E = \sum_{i}^{n} E_i = \sum_{i}^{n} (EF_i * AF_i)$$

- **EF$_i$** Emission factor, expressed as a volume flow rate in standard cubic meters per kilometers of network length.
- **AF$_i$** Activity factor expressed as the length of the network in kilometers.

The total emissions are the sum of all different emissions estimated by every material, where *i* is the source of emissions, the different materials and *n* is the number of the different materials composing the network.

Natural gas emission estimation (scm)	Steel		Polyethylene		Cast iron		
Year	MP	LP	MP	LP	MP	LP	TOT
2018	2.510.335	838.115	154.715	68.702	0,00	244.826	3.816.694
2019	2.512.756	838.441	155.178	70.133	0,00	242.377	3.818.887
2020	2.596.151	898.333	160.237	74.095	0,00	239.448	3.968.267
2021	2.597.693	899.016	160.292	78.331	0,00	236.980	3.972.314
2022	2.596.826	899.871	160.514	84.323	0,00	234.810	3.976.346
2018-2022	12.813.764	4.373.778	790.939	375.586	0,00	1.198.442	19.552.510

Notes: Results given by equation (1) crossing the data related to the network length and the EF estimated by ISPRA, divided in different materials.

Table 12. Estimate emissions of natural gas from generic emission factor

The emissions calculated are not methane emissions but natural gas emissions, and in order to get methane emissions out of that the percentage of methane in the mix has to be taken into account, which is, as mentioned above.

The complete equation then would look like this:

$$E = \sum_{i}^{n} E_i = [\sum_{i}^{n} (EF_i * AF_i)] * \rho_{ch4} \quad (27)$$

With p_{ch4} being the percentage of methane present in the natural gas mix flowing in Italian pipelines, equal to the 92% of the current Italian natural gas mix, as it has been calculated by ISPRA in the National Inventory Report (2022) from the data ISPRA has collected by Snam for 2022.

Methane emission estimation (m^3)	Steel		Polyethylene		Cast iron		
Year	HP/MP	LP	HP/MP	LP	HP/MP	LP	TOT
2018	2.309.508	771.066	142.338	63.205	0,00	225.240	3.511.358
2019	2.311.736	771.365	142.764	64.523	0,00	222.987	3.513.376
2020	2.388.459	826.467	147.418	68.167	0,00	220.292	3.650.805
2021	2.389.878	827.095	147.469	72.065	0,00	218.021	3.654.529
2022	2.389.080	827.881	147.673	77.577	0,00	216.025	3.658.238
2018-2022	11.788.662	4.023.876	727.664	345.539	0,00	1.102.567	17.988.309

Notes: Estimated methane emissions divided in materials and operating pressure for every year estimated by crossing the Company network length and the emission factor for every material and operating pressure and the generic emissions factors (ISPRA)

Table 13. *Estimate emissions of methane from generic emission factor*

The above methodology provides generic estimates, not keeping into account the number of leaks or the value of those leaks in terms of methane flow, especially not accounting for the high number of leaks happening aboveground where external factor have a higher impact on the network strength.
Is it also true that such estimates provide basic information with reliable foundations to start the estimation and have a general idea of the magnitude of the emissions coming from a certain network.

3.4.2 Current time overview

Generic emission estimations allow for basic knowledge while for a more in-depth understanding emissions should be estimated at the source level.
The methodology is similar but different factors are taken into consideration, as both the activity factor and the emission factor are calculated and estimated differently.
As afore-mentioned the source-level estimation is a methodology that grants the possibility to further divide the estimation into two different parts, related to the pre-localization and post-localization of leaks, enabling the possibility to in-depth analysis of the various factors related to emissions.

$$E = \sum_{i}^{n} E_i = \sum_{i}^{n} (EF_i * AF_i) \quad (1)$$

Going back to the general emission estimation formula there are two main factors that have a direct correlation with the emission results:

- EF
- AF

The emission factor is specific for every leak, and as of now, without better reporting and on-field measurements it is not possible to use that as true differentiating factor, since the estimations will be run with estimated emission factors that are source-related.
The activity factor on the other hand is calculated as:

$$AF_i = N_i * t_i \quad (2)$$

Where N[81] is the number of leaks found by the company within the network managed by the company while t is the time every leak is kept open emitting.

While both the emission factor and the number of leaks is random, depending on the leak itself and not in control of the company, the time a leak is emitting is partially in control of the company.

This is the reason why the time it has been chosen as the differentiating factor for the two analysis that will be performed, dividing the emissions into pre-localization and post-localization

While it is not possible to decide or decrease the number of leaks, without interventions onto the network, or the volume of emissions that are emitted by every leak, it is certainly possible to decrease the amount of time leaks are kept emitting working on decreasing the existence of leaks.
Understanding the separate impact of the two leak timelines enables the possibility to study and analyze the different actions that both the policymaker and companies can undertake to efficiently act on emission abatement.
The differentiation of the analysis grants the possibility to split the phases of emission timings understanding the different factors that directly affect every phase's increases in emission time underlying possibilities to decrease such timing both in policy actions and company

[81] Annex II.II tables from XVIII to XXI

To better understand the different time factors part of the overall existence time the different phases of a leak overall time have been defined as follows:

- Incubation time: time that represent the full pre-localization portion of the existence of a leak divided in:
    - Latency time[82]: time in which the leak is not known to be existing, starts with the beginning of the emitting events and lasts until its pre-localization.
    - Localization time[83]: time the company needs, once the leak has been pre-localized, to localize the precise location of the leak.
- Elimination time: time that represents the phase in which a leak is located and eliminated
    - Scheduling time[84]: time the company waits to intervene onto the leak and start repairing operations.
    - Repair time[85]: time required by the company to repair the leak.

Every phase has to be specifically targeted since each of them has specific needs and factors that affect their outcome.
The main difference is the fact that in the pre-localization phase the efforts of the company are not about eliminating and repairing leaks but focus on inspecting the network in order to find possible leaks and once leaks are found to be happening the second part regards the efforts shift onto the localization, that will eventually lead to a classification and elimination.
The value of t will then be splitted into two values, which in turn will be divided in two values respectively:

$$t = t_1 + t_2 = t_{1a} + t_{1b} + t_{2a} + t_{2b}$$

Where:

- t is the total time a leak is emitting
- t_1 is the pre-localization time or incubation time phase of a leak
- t_2 is the post-localization time or elimination time phase of a leak
- t_{1a} is the latency time phase of a leak
- t_{1b} is the localization time phase of a leak
- t_{2a} is the scheduling time phase of a leak
- t_{2b} is the repair time phase of a leak

[82] Annex II.II tables from XXII to XXV
[83] Annex II.II table XXVI
[84] Annex II.II tables from XXVII to XXX
[85] Annex II.II table XXXI

3.4.2.1 Pre-localization time analysis

The latency time corresponds to the time a leak is not know to be existing, and represents the time that the company estimates the leak has been leaking before being smelled, felt or heard, or found with sensors. By design latency time is mostly estimated and, as of now, cannot be known precisely, and it's estimation is based on assumptions related to the pre-localization method.

A leak can be pre-localized in two different manners as afore-mentioned in the previous chapter: by scheduled inspections performed regularly by the company on the network or by the communication of a possible leak made by third parties to the distribution company managing that area.

The main quantitative time-related difference between the two paths of pre-localization are related to the assumptions that precede and support the estimation of the latency time.

A leak notified by third parties (TPN), as stated by company's technical documents[86], is assumed to have no latency if some aspects are met:

- It is supposed that all notifications by third parties on aboveground leaks lead to an immediate communication, the operators intervention is required to happen within one hour.
- It is supposed that notification by third parties on underground leaks found to have a volumetric concentration higher than 3,5% lead to an immediate communication, due to the considerable flow of gas that is assumed to be leaking.
-

That is assumed due to the fact that a leak that is smelled, heard or felt has an enough consistent volume to be pre-localized immediately after the start of the emission and supposedly the localization process would start in one hour which is the maximum amount of time the regulator grants to the distribution operator to start localization procedures after a leak notification.

While notified leaks have a supposed shorter latency time overall, leaks that arise from company scheduled inspections (CSI) of the network are treated differently, with some differences depending on the volume of the methane leaking:

- It is supposed that aboveground leaks that have been pre-localized during an inspection found to have a volumetric concentration higher than 3,5% would have been notified immediately if the inspection team was not there to find it, hence is treated as such.
- All other leaks found during inspections are treated grouping them to the closest pipe associating them to the frequency of inspection of the closest network, in order to approximate the existence of the leak before its pre-localization.

[86] Company assessment "Metodologia_calcolo_volumi"

The second factor composing the incubation time is the localization time that differs from source to source with aboveground leaks and gas meter leaks being the easiest to locate while on average underground leaks, divided in pipeline and components, require the most time.

Average localization time (h)			
Aboveground	Gas meter	Components	Network
5,1	1,6	266,7	308,9

Notes: The average localization time is estimated from company data as the average time needed to locate a leak depending on its source, and it is calculated as an average of the data gathered during the five years that are taken into consideration for the analysis, and expressed in hours.
Company dataset, *Dati tecnici*; *Tempo localizzazione eliminazione* (2024)

Table 14 *Average localization time*

Table 3 gathers all the time data regarding incubation time, dividing the total number of leaks eliminated by the company during the five years span (41.300) in priority, source and prelocalization methods, which are the different variables that are used to group the leaks.
The priority of a leak is used as a qualitative value to assume the volumetric concentration of a leak, in fact immediate priority leaks have been given a volumetric value higher than 3,5% that helps with the association of a certain latency time as expressed above.
The source[87] is related to both the latency time and the localization time, as aboveground (aboveground leaks and gas meter) and underground leaks (pipelines and components) have different latency time with respect to their location on the network and different sources have whole different average localization times, table 5.
Aboveground leaks are all leaks that are located on open air, delivering gas at the end of the distribution process, operated in low pressure, mainly in private properties or close to the end consumer of the service while gas meter leaks are the leaks that only happen inside gas meter stations, as the name suggests.
Pipeline leaks are leaks that regards the pipeline underground network, where natural gas flows out of connections in between pipes, while those related to components are fugitive emissions coming out of valves or flanges that lose their grip and failing to hermetically grant the passage of natural gas. Both sources can be operated in medium and low pressures, in bigger pipelines than those that characterize aboveground leaks, both sources refer to leaks that happen below the ground level as the name suggests.
The max latency time equals the maximum time that exists between the inspection of the same point of the network with the inspection frequency[88] that the company assess to have.

$$Max\ latency\ time = \frac{Network\ length}{Network\ inspected} * 8760\ h$$

[87]Arera (2019)
[88]Arera (2019)

The pre-localization methods is related, as explained above in the paragraph, to the latency time, as the different methods with which the company learns about the presence of a leak in its network determines the value of the latency time, either 1 hour or 15.619 hours.
The value for the latency time is given by dividing the total network length managed by the company by the network inspected yearly and then calculating the hours that divide the two points in time, and over the five years that are interested by the analysis is equal to 15.619 hours, which is the value resulted from the average yearly latency time estimated[89].
The values reported on table 6 are average values for the five years examined, estimated by taking the average time value for the years examined and are not the values that will be used to estimate the emissions, the use of table 6 is an overview of the different phases, while the estimation will be performed with year to year data limiting average values to the minimum in order to decrease the already present uncertainty.
The data presented have the aim to show an overview of the current incubation time in order to have a first glance to those leaks that exhibits higher incubation times, and the effect of latency time over the total incubation time, incorporating also the leak number to give an idea of the amount of leaks for each categories that have been analyzed.
The impact on the incubation time given by the latency time is clear, as all leaks that have not the 1 hour value as latency time present a much higher total incubation time, even those that have higher localization times such as underground pipelines and components leaks.
The minimum value observed is the incubation time that regards gas meters of immediate priority as well as those notified by third parties, while the maximum value is related to pipeline leaks due to the combination of the maximum latency time and their high localization time.

[89] Average value derived from the yearly maximum latency time; see Annex II.II, tables from XXII to XXV

	Priority	Source	Pre-localization method	Leaks number	Latency time (h)	Localization time (h)	Incubation time (h)
Current leak incubation overview	Immediate priority (A1)	Aboveground	TPN	5.307	1,0	5,1	6,1
			CSI	1.177	1,0	5,1	6,1
		Pipelines	TPN	118	1,0	308,9	309,9
			CSI	837	15.619,7	308,9	15.928,6
		Components	TPN	1.246	1,0	266,7	267,7
			CSI	56	15.619,7	266,7	15.886,4
		Gas meter	TPN	4.595	1,0	1,6	2,6
			CSI	483	1,0	1,6	2,6
	High priority (A2)	Aboveground	TPN	49	1,0	5,1	6,1
			CSI	10	15.619,7	5,1	15.624,8
		Pipelines	TPN	76	15.619,7	308,9	15.928,6
			CSI	516	15.619,7	308,9	15.928,6
		Components	TPN	76	15.619,7	266,7	15.886,4
			CSI	151	15.619,7	266,7	15.886,4
	Medium priority (B)	Aboveground	TPN	36	1,0	5,1	6,1
			CSI	4	15.619,7	5,1	15.624,8
		Pipelines	TPN	46	15.619,7	308,9	15.928,6
			CSI	1.267	15.619,7	308,9	15.928,6
		Components	TPN	100	15.619,7	266,7	15.886,4
			CSI	340	15.619,7	266,7	15.886,4
	Low priority (C)	Aboveground	TPN	14.374	1,0	5,1	6,1
			CSI	2.104	15.619,7	5,1	15.624,8
		Pipelines	TPN	202	15.619,7	308,9	15.928,6
			CSI	1.276	15.619,7	308,9	15.928,6
		Components	TPN	287	15.619,7	266,7	15.886,4
			CSI	644	15.619,7	266,7	15.886,4
		Gas meter	TPN	5.381	1,0	1,6	2,6
			CSI	542	15.619,7	1,6	15.621,3

Notes: In order: Priority classes divided in A1, A2, B and C; source of the emission, divided in aboveground, underground pipelines, underground components and gas meters; pre-localization method divided in TPN and CSI; leak number relatively to the priority class, the source and the pre-localization method; latency time expressed in hours depending on the pre-localization method; the localization time, expressed in hours, relative to the source of the leak; the incubation time as the sum of the latency time and the localization time, expressed in hours.

All time values are exhibited as the average of the yearly values, for the years from 2018 to 2022.

__Table 15__ Current leak incubation time overview

3.4.2.2 Post-localization time analysis

Once a leak has been localized the companies classify it based on the threat it poses to the society, and from that moment onwards the duration of the leak is a voluntary choice made by the company following the directions of the regulator.
Unlike pre-localization time assessment the post-localization is not estimated, as the company knows the precise timing they take to eliminate a leak, dividing it in scheduling time and repair time.
The scheduling time depends mostly on the priority that is given to the leak, as an increase in priority leads to a decrease in time granted to the company to repair the leak.
As mentioned before in the document, the current prioritization of leak elimination procedures is based on the physical threats posed by leaks, particularly the risk of the creation of an explosive mix in confined spaces, as methane, having a lower flammable point (LFL) of 3,5%, can ignite easily. Therefore, leaks in which gas can easily accumulate to create explosive mixtures are given immediate attention and are prioritized for elimination within a maximum of 24 hours.
In contrast, leaks that do not present a direct public threat are assigned lower priority, with elimination timings based on their potential danger. Leaks that could become future hazards and are located near fixtures or cavities receive high priority; leaks that pose no immediate threat but are close to fixtures or cavities are given medium priority; and leaks that are no threat due to their location in open air receive low priority, with a maximum elimination timeframe of 180 days.
The current priority classes are:

Code	Priority class	Time allowed for elimination
A1	Immediate priority	24 hours
A2	High priority	7 days
B	Medium priority	30 days
C	Low priority	180 days

Notes: Priority classes are established by the physical threat the leak poses, the higher the threat posed by the methane emitted through the leak the smaller the time granted to the company to repair the leak.

__Table 16__ Current leak elimination priority classes

The company is allowed to push back and delay all leak repair operations until the end of the period granted by the regulator, hence increasing the scheduling time for each leak, and the results of the scheduling time depend mostly on the practices and the possibility of the company to repair the leaks.
The value for A1 leak scheduling time has been stated as one hour, which is the time granted to the company to reach the location of the leak to start immediate repair.
The estimation of the scheduling time for every source in every priority class is estimated as the average elimination time for the 5 years time span analyzed, minus the average time estimated to be required by the company to repair suck leaks.
The source of the leak is on the other hand is related to the repair time which does not change over the different priority classes but depending on the location of the leak.

Leak that happen above the ground have a shorter repair time given by the easier access to the leak and by the smaller complexity of leak repair operation, while on the other hand underground leaks present a higher value expressing the difficulties relate to operation under the level of the surface.
Repair time is estimated to be equal at the time that the company spends repairing immediate priority leaks, that supposedly have no scheduling time other than the time needed to gather the operation time and drive to the leak location, that is the reason why the repair time is estimated to be the same for every priority class.
Table 5 presents the current overview of scheduling time, repair time and elimination time for the post-localization existence of leaks, dividing the number of leaks in just priority classes and sources as those are the two variables that have effect on the choice and the estimation of the factors related to the time.

	Priority	**Source**	**Leaks number**	**Scheduling time (h)**	**Repair time (h)**	**Elimination time (h)**
Current leak elimination overview	Immediate priority (A1)	Aboveground	6.484	1,0	0,5	1,5
		Pipelines	955	1,0	4,6	5,64
		Components	1.302	1,0	4,6	5,56
		Gas meter	5.078	1,0	0,4	1,4
	High priority (A2)	Aboveground	59	25,7	0,5	26,2
		Pipelines	592	58,9	4,6	63,5
		Components	227	70,5	4,6	75,11
	Medium priority (B)	Aboveground	40	96,7	0,5	97,2
		Pipelines	1313	383,7	4,6	388,4
		Components	440	333,8	4,6	338,4
	Low priority (C)	Aboveground	16.478	149,6	0,5	150,1
		Pipelines	1478	962,8	4,6	967,4
		Components	931	974,9	4,6	979,5
		Gas meter	5.923	7,7	0,4	8,1

Notes: In order: Priority classes divided in A1, A2, B and C; source of the emission, divided in aboveground, underground pipelines, underground components and gas meters; leak number relatively to the priority class and the source; scheduling time expressed in hours depending on the priority class and the source; the repair time, expressed in hours, relative to the source of the leak; the elimination time as the sum of the scheduling time and the repair time, expressed in hours.
All time values are exhibited as the average of the yearly values, for the years from 2018 to 2022.

***Table 17** Current leak elimination time overview*

The viewer only needs a glance at table 7 to understand the differences between the elimination time, that is equal to the post-localization time, and the incubation time, equal to the pre-localization time, showed in table 6.
Among the for time factor analyzed nothing gets close to the latency time as the repair time ranges between a minimum value of 0,4 hours for the repair of gas meter leaks, and 4,6 hours which is the time needed to repair both underground type leaks. A bigger impact on the elimination time is given by the scheduling time that from a flat lowest point of 1 hour for A1 classified leaks, has a maximum

estimated time of 974,9 hours for the scheduling of repair operations, granted by their belonging to C priority class, that has 180 days of scheduling allowed by the regulator.
While all other timings are mildly related to policymakers decisions, latency time can be related to it as well but it will talked about later on in the discussion, scheduling time is all about compliance to policy standards, creating opportunities to the policymaker to intervene positively.

3.4.3 Source emission estimation

The source emission estimation grants the possibility to understand what leak source in what phase of its existence has the major impact over the total emissions that arise from the distribution of natural gas, creating insights and opportunities for the policymaker, as well as company's operatives to intervene abating methane fugitive emissions.
In order to perform the estimations the time of existence of a leak has to be multiplied by the emissions that are estimated to be escaped out of that leak, hence a value that expresses the volume per time of methane emitted by a leak.
The emission factor expressing the volume per time of methane emitted by specific leaks have been estimated from different sources, diving them in underground, comprising underground pipelines and underground components, aboveground and gas meters.
The emission factor represents the volume of natural gas released per unit of time, and for the purposes of this analysis, the unit of time used is the hour as all time-related estimates are expressed in hours and rounded to one decimal place.
The estimated emission factors (EFs) for the four leak sources considered in this study were derived from a combination of sources, including published literature (GERG[90], MEEM, 2018; ISPRA, NIR[91], 2023), company documentation (Inrete, Estimation Methodology, 2020), and the professional expertise of distribution system executives.
These emission factors are summarized as follows:

Source	**Leak number**	**Emission factors (scm/h)**
Aboveground	23.061	0,01
Underground	7.238	0,23
Gas meters	11.001	0,005

Notes: The Emissions factor are expressed as standard cubic meter of neutral gas leaking out of the leaks by the different sources.
Data derived from
Methane emission estimation method for the gas distribution grid, European gas research group (2018)
National inventory report, Istituto superiore per la protezione e la ricerca ambientale (2024)

Table 18 *Emission factors*

[90] The project Methane Emission Estimation Method for the Gas Distribution Grid (MEEM) is the second phase of the project Analysing the Methods for Determination of Methane Emissions of the Gas Distribution Grid which was initiated in November 2014 by members of the European Gas Research Group (GERG). The project was motivated by the target to improve the accuracy and reliability of national emission estimations, the transparency of the associated results, and consequently the reputation of natural gas in general.
[91] The National Inventory report (NIR) helps international processes of verification and reporting with official estimates of greenhouse gas, especially examining the transparency, consistency and accuracy in the realization of the qualities explicitly requested by ISPRA.

Aboveground components have a significantly lower emission factor, estimated at 0.01 scm/h, due to the minimal pressure differential between atmospheric pressure (1.0 bar) and the low operating pressure of these network components (approximately 1.005 bar). This limited pressure gradient significantly reduces the rate of natural gas emissions.
Gas meters exhibit an even lower emission factor, set at 0.005 scm/h, despite operating under similar pressure assumptions. This is due to the specific nature of their emission sources, that by design typically exhibit smaller pressure differences and are often located within private properties, further mitigating the release rate of natural gas
In order to estimate both aboveground and gas meter emissions factors the estimations provided by the literature have been crossed with the expertise of Company operators, to have a more ad-hoc factor to estimate emissions, that would fit the network that was examined in the document.
As observed in Table 9, all underground sources, such as pipelines and components, have been grouped into a single "underground" category, as leaks from these sources are estimated to have a similar hourly emission impact, being the highest on the list. This value was estimated by using a reverse engineering method on the data published by ISPRA in the Greenhouse gas inventory.
ISPRA presented an emission factor related to the standard cubic meter of natural gas emitted for every kilometer of pipelines, from this values the total estimated emissions related to the underground network have been calculated and out of that value it was possible to work the way back for the unit/time emission factor by using the total amount of hours that such leaks were estimated emitting, resulting in the value showed in the third row, the value has been also cross checked with engineeristic calculation on the volumetric flow rate given by company technical guidelines, verifying the robustness of the estimation.
The value has been estimated as the average result of the calculation for the five years taken into consideration:

Year	**Underground emission factor (scm/h)**
2018	0,26
2019	0,19
2020	0,21
2021	0,24
2022	0,25
Average	0,23

Notes: Tab 19 shows the yearly underground emission factors expressed as methane emitted per unit of time that in the documents as been estimated using one hour, and on the lower row the average of the five year span value.

Table 19 *Underground emission factors*

Table 19 shows a steady trend over the years with a down year 2019, caused by a decrease in emission summed to a high number of leaks repaired and a higher emission factor registered in 2018 for the opposite reasons, those factors offset each other as the average without counting those two possible outliers deviates only by 0,6 standard cubic meters, 0,227 to 0,233, from the average of the whole five years.

3.4.3.1 Pre-localization emission estimation

After the time analysis it is possible to cross the emission factor showed before to estimate the emissions coming out of the network, dividing them in the leak existence phases that have been outlined in the previous chapters, and by doing so it is possible to understand the different impacts and the emission values that every phase accounts for.

$$E = \sum_{i}^{n} E_i = \sum_{i}^{n} (EF_i * AF_i) * 92\% \quad (1)$$

In this case AF will be resulting from the multiplication of N by the two time values relative to the incubation phase of the leak:

- t_{1a} as the latency time value, which depends on the pre-localization methods
- t_{1b} as the localization time phase of a leak, which depends on the source of a leak

In this chapter the main protagonists will be the emissions arising during the pre-localization phases of existence of a leak, those that have been showed to be the most consistent over the whole life of an emitting source in the distribution stage.

The two phases that will be estimated are the latency time[92], in which the leak is not known by the company and the localization time[93], which is equal to the time a leak is known to be existing but it has not been localized.

The estimation has been carried out in two different directions, for each specific phase of the incubation time of a leak, with one focussing on the impact the two pre-localization methods and the second one based on the impact of the emission coming from every source.

The results then are summed up to give a complete overview of the emitting current situation for what regards every leak in its incubation existence.

Pre-localization methane estimated emissions m^3			
Years	TPN	CSI	Total
2018	560.823	2.446.718	3.007.542
2019	560.413	3.566.718	4.127.132
2020	627.221	3.244.890	3.872.112
2021	591.848	2.939.011	3.530.860
2022	441.385	2.858.439	3.299.824
Total	2.781.692	15.055.779	17.837.472

Notes: Estimation derived from Company data related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by pre-localization method: Third party notified (TPN) and company scheduled inspections (CSI)

Table 20 *Pre-localization estimated emissions*

[92] Annex II.II tables XXII to XXV
[93] Annex II.II table XXVI

Table 20 and table 21 show different approaches on the display if estimated emissions with the former exhibiting the pre-localization methodology dividing the estimated emissions in third party notified leaks and company scheduled inspection while the latter shows the different sources.
Crossing the two tables we can assess that those with the higher impact are, as expected by the assumptions, the emissions coming out of leaks that are pre-localized by third party notice that, despite being the vast majority of all leaks, 79% of all leaks repaired during the five-year period in analysis, are those with the lower impact among the two groups in table 8, while among sources that accounting for the higher share of emissions is estimated to be the underground pipeline source, followed by the other underground source of the components.

Pre-localization estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	44.172	12.422	926.931	2.024.016	3.007.542
2019	32.192	9.684	1.268.936	2.816.318	4.127.132
2020	72.622	9.050	1.333.991	2.456.447	3.872.112
2021	105.210	4.453	1.059.965	2.361.230	3.530.860
2022	49.869	3.994	1.047.230	2.198.730	3.299.824
Total	304.066	39.606	5.637.055	11.856.744	17.837.472

Notes: Estimation derived from Company data related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 21 *Pre-localization estimated emissions*

More in depth analysis shows the higher impact of the emissions caused during the latency phase of a leak that over the years account for more than 97% of all emissions coming out of the pre-localization existence of a leak, showing how important a complete knowledge of a network is to prevent emissions.

Pre-localization estimated methane emissions m^3 - share of leak existence phases					
Years	Latency time	Localization time	Total	% Incubation	% Localization
2018	2.949.021	58.520	3.007.542	98,05%	1,95%
2019	4.022.774	104.358	4.127.132	97,47%	2,53%
2020	3.766.688	105.423	3.872.112	97,28%	2,72%
2021	3.439.408	91.452	3.530.860	97,41%	2,59%
2022	3.207.478	92.346	3.299.824	97,20%	2,80%
Total	17.385.371	452.101	17.837.472	97,47%	2,53%

Notes: Estimation derived from Company data related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by leak existence phase and share of the estimation over the total

Table 22 *Pre-localization estimated emissions - share of phases*

3.4.3.1 Post-localization emission estimation

Similarly at what has been done in the previous chapter it is possible to cross the emission factor showed before to estimate the emissions coming out of the network, dividing them in the leak existence phases that characterize the post-localization phase, that in the document has been also called elimination phase, outlining the results for both the scheduling phase and the repair phase understanding the different impacts and the emission values that every phase accounts for.

$$E = \sum_{i}^{n} E_i = \sum_{i}^{n} (EF_i * AF_i) * 92\% \quad (1)$$

In this case AF will be resulting from the multiplication of N by the two time values relative to the elimination phase of the leak:

- t_{2a} as the scheduling time value, which depends on the elimination priority of a leak
- t_{2b} as the repair time phase of a leak, which depends on the source of a leak

In this chapter the main protagonists will be the emissions arising during the post-localization phases of existence of a leak as mentioned, which are the least impactful but those to which the company has the easier intervention since the leak is known to be emitting and it's localized.
The two phases that will be estimated are the scheduling time[94], in which the leak is known and localized and its repair is planned and scheduled by the company and the repair time[95], which is equal to the time needed by the company to repair the leak.
The estimation has been carried out in two different directions, for each specific phase of the elimination time of a leak, with one focussing on the impact the different priority classes have and the second one based on the impact of the emission coming from every source.
The results then are summed up to give a complete overview of the emitting current situation for what regards every leak in its incubation existence.

Post-localization estimated methane emissions m^3					
Years	A1	A2	B	C	Total
2018	735,33	2.072,37	16.987,83	91.984,76	111.780,30
2019	557,71	3.504,30	32.175,69	114.884,21	151.121,90
2020	382,63	2.890,31	25.573,06	101.180,96	130.026,96
2021	517,43	1.786,70	28.149,89	95.470,59	125.924,61
2022	587,71	1.558,07	37.621,27	110.447,90	150.214,94
Total	2.780,81	11.811,75	140.507,74	513.968,42	669.068,72

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by priority classes: Immediate priority (A1), High priority (A2), Medium priority (B) and low priority (C).

Table 23 *Post-localization estimated emissions*

[94] Annex II.II tables from XXVII to XXX
[95] Annex II.II table XXXI

Table 23 and table 24, as has been done in the previous chapter, show different approaches on the display if estimated emissions with the former exhibiting the post-localization division methodology by dividing the estimated emissions in priority classes while the latter divides the estimated emissions by leaks source.
Table 23 shows how, as expected by the regulatory requirements, the higher the priority, the higher the time spent delaying the repair of a leak, the longer the schedule time phase lasts, the higher the amount of methane emitted by the leaks during the scheduling phase

Post localization estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	3.487,29	215,59	35.977,21	72.100,20	111.780,30
2019	2.898,10	29,95	51.295,93	96.897,92	151.121,90
2020	5.316,00	25,53	46.580,41	78.105,02	130.026,96
2021	7.958,85	30,03	40.480,41	77.455,33	125.924,61
2022	3.711,17	6,94	53.443,14	93.053,69	150.214,94
Total	23.371,41	308,05	227.777,09	417.612,17	669.068,72

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 24 *Pre-localization estimated emissions*

Table 24 on the other hand shows how much more impactful are leaks that arise from underground sources that have a both singular higher average scheduling time with respect with other source and repair time, that sums up to the values showed.
More in depth analysis shows the higher impact of the emissions caused during the scheduling phase of a leak that over the years account for almost 99% of all emissions coming out of the post-localization existence of a leak, showing how impactful is the role that the time granted by the regulator to eliminate leaks.

Post localization estimated methane emissions - shares of leaks existence phases					
Years	Scheduling time	Repair time	Total	% Scheduling	% Repair
2018	110.043,35	1.736,95	111.780,30	98,45%	1,55%
2019	149.490,56	1.631,35	151.121,90	98,92%	1,08%
2020	128.954,46	1.072,50	130.026,96	99,18%	0,82%
2021	124.667,98	1.256,64	125.924,61	99,00%	1,00%
2022	148.819,45	1.395,49	150.214,94	99,07%	0,93%
Total	661.975,80	7.092,92	669.068,72	98,94%	1,06%

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by leak existence phase and share of the estimation over the total

Table 25 *Post-localization estimated emissions - share of phases*

3.4.3.3 Total emission estimation

To understand the total magnitude of the emission the Company is responsible for in its natural gas distribution operations the pre and post localization emission estimations have to be summed up. Summing up the two different can be used to gather two different, but equally important insights, that have already been mentioned in the previous chapters:

- Understand the overall magnitude of fugitive methane emissions that leak through the distribution channels managed by the company, in order to have an idea of the impact of fugitive methane emissions
- Understand which phase of leaks existence is more dangerous in terms of economic and environmental losses in order to assess which one has to be prioritized.

Total estimated methane emissions m³					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	47.659,29	12.638,51	962.908,89	2.096.116,38	3.119.323,07
2019	35.090,82	9.714,76	1.320.232,40	2.913.216,55	4.278.254,54
2020	77.938,39	9.076,03	1.380.571,85	2.534.552,96	4.002.139,23
2021	113.169,05	4.483,48	1.100.446,30	2.438.686,15	3.656.784,98
2022	53.580,71	4.001,44	1.100.673,34	2.291.784,24	3.450.039,74
Total	327.438,26	39.914,22	5.864.832,80	12.274.356,28	18.506.541,56

Notes: Estimation derived from Company data related to the sum or the different phases of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 26 *Total estimated emissions*

Table 26 shows the overall emissions grouping them by the different emitting source, exhibiting the higher impact of of underground leaks, as seen before, and the close-to-zero impact of gas meters when it comes to emissions.

Between underground sources pipelines leaks are found to be the most emitting more than doubling their counterpart, components, every year in a steady trend.

Years	Incubation time	Elimination time	Total	Incubation time %	Elimination time %
2018	3.007.542,77	111.780,30	3.119.323,07	96,42%	3,58%
2019	4.127.132,64	151.121,90	4.278.254,54	96,47%	3,53%
2020	3.872.112,27	130.026,96	4.002.139,23	96,75%	3,25%
2021	3.530.860,37	125.924,61	3.656.784,98	96,56%	3,44%
2022	3.299.824,80	150.214,94	3.450.039,74	95,65%	4,35%
Total	17.837.472,84	669.068,72	18.506.541,56	96,38%	3,62%

Notes: Estimation derived from Company data related to the different phases of methane emissions expressed in cubic meter of methane emitted,, divided by leak existence phase and share of the estimation over the total

Table 27 *Total estimated emissions - share of phases*

From table 27 it is clear the impact of the incubation time estimated emissions over the overall emissions related to the whole existence of a leak.

The incubation time of the leak existence makes up for a steady 96% of overall emissions, incubation time that is mainly composed by the latency phase of the leaks.

3.4.3.4 Result discussion

The different phases volumes show some interesting insights.
Although being the easiest to intervene to the localization, scheduling and repair timing are those with the lowest impact over the total emissions.

Years	Latency phase %	Localization phase %	Scheduling phase %	Repair phase %
2018	94,54%	1,88%	3,53%	0,06%
2019	94,03%	2,44%	3,49%	0,04%
2020	94,12%	2,63%	3,22%	0,03%
2021	94,06%	2,50%	3,41%	0,03%
2022	92,97%	2,68%	4,31%	0,04%
Total	93,94%	2,44%	3,58%	0,04%

Notes: Share percentage of every phase of a leak existence over the total emissions that have been estimated previously in the document

Table 28 *Share of phases over the totality of emissions*

The absolutely predominance of the latency phase of the leaks, which is the leak existence phase where the company hs the lowest impact shows clearly that improvements have to be made in locating leaks, either increasing the frequency of inspections, improving the channels through which citizens are allowed to notify leaks or develop or invest in technologies that grant a more complete network control and management.
On the bright side, the low impact of the other phases that are, in different ways, controlled by the Company shows a positive effort that comes from Company practices.
While there is the need for a decisive change in leak detection, which would decrease the latency phase, the improvements that can be made on other phases, especially on the scheduling phase are not to be underlooked since they can grant further methane emission abatement, as it will be discussed later in the document, by adding the environmental impact as a factor for leak elimination prioritization, changing the current physical safety-driven priority classes with a more holistic approach that accounts both for end-users safety and environmental approach.
Leak detection as it has been mentioned before in the document is mainly connected with the pre-localization method with which leaks are located: third party notified leaks and company scheduled inspections, with the former related to the amount of help companies receive from the citizen locating leaks and the latter related to the amount of network the company is able to inspect over the time.
The actions that could be undertaken on leak detection can have two paths, both with the aim to increase the speed at which leak are found once they start emitting, with one focusing on increasing the rate of kilometres inspected and the other improving the engagement of citizens in leak detection.
Increasing the rate of inspection might be the easiest to target since the company would only need to increase the number of personnel dedicated to leak detection but the most expensive due to the high personnel costs that such path would embed and the results won't be as game changing as it could be expected. On the other hand citizen engagement could lead to a steeper decrease, based on the assumptions that have been made for TPN leaks, as the localization of a leak by third party have a huge impact on its latency time. Citizen engagement will be another interesting aspect to incorporate and analyze along the document, examining the possible benefits of increased citizen engagement in leak detection.

3.4.4 Maximum time granted - a comparison

Policies are important to tackle emissions, this is known, but it is interesting to understand how important such policies are and the impact they have in reality.
In this paragraph, it will be analyzed and estimated the emissions that would arise if companies would use all the time granted by ARERA in its regulation.
The variables changing would be t_1 and t_2 of the activity factor, which instead of being represented by Company values will be estimated from the maximum values allowed by the regulator, allowing for a comparison of the company performances against the maximum allowed performances by the regulatory body.
In order to estimate t_{1a} for leaks that are pre-localized through company scheduled inspections, it has been calculated the weighted average between the maximum allowed time for the part of network with mandatory yearly inspections (8760 h) ,involving 14% of all the network, and the maximum allowed time for the inspection of the remaining 86% of the network, which is a three year time[96] (26280 h).

$$t_{1a_{max}} = 8760 * 0,14 + 26280 * 0.86 = 23827,20\, h$$

This change will affect the latency time that instead of the values derived by the Company inspection scheduling performances will be estimated by using the t_{1aMax}, that will be used as a flat t_{1a} value for every year since the requirements set by the regulator did not change over the years analyzed in this document. The change in time between the inspection of a point of the network is due to the fact that the regulator allows a smaller scheduled inspection frequency, hence increasing the time that exists between the inspection of the same point in the network.
For the estimate of the scheduling time t_{2a} on the other hand, the estimation of the time granted by the regulator was easier since the values on which was based the estimate were the specific time guidelines of the CIG dealing with fugitive emissions

- A1: 24 hours
- A2: 7 days or 168 hours
- B: 30 days or 720 hours
- C: 180 days or 4320 hours

The value for t_{2a} hence is estimated by substituting the current company elimination time by the maximum time granted by the regulator for the elimination relative to every priority, meaning that while the repair time will be kept the same as for the company performance estimation the scheduling time will be the one changing from:

$$t_{2a\ company} = t_{2\ company} - t_{2b\ company}$$

to

$$t_{2a\ max} = t_{2max} - t_{2b\ company}$$

[96] Arera, *Regolazione della qualità dei servizi di distribuzione e misura del gas per il periodo di regolazione 2020-2025, ,* art. 14, comma 2

and it will be calculated as the difference between the maximum elimination time grated and the repair time of the Company.
The increase in time values will effect the whole estimations both in pre and post-localization time existences of the leak, and in the next this chapter the differences will be explored by estimating the maximum allowed emissions and confronting them with the current estimated performances of the Company.

Maximum estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	179.235,60	51.164,07	1.522.334,85	3.275.153,77	5.027.888,28
2019	153.637,82	39.844,07	2.051.016,53	4.450.951,23	6.695.449,64
2020	232.061,86	36.797,52	2.162.693,80	3.921.456,73	6.353.009,92
2021	323.923,86	27.598,81	1.819.654,55	3.982.408,72	6.153.585,94
2022	233.372,50	22.396,53	1.882.375,99	3.883.756,94	6.021.901,96
Total	1.122.231,64	177.800,99	9.438.075,73	19.513.727,38	30.251.835,74

Notes: Estimation derived by substituting the Company data relative to latency time and scheduling time with the maximum time granted by the regulator from the minimum required inspection frequency and the maximum time granted for leak elimination.

Table 29 *Maximum estimated emissions*

Once the estimation resulting from the changes brought by the different latency and scheduling time is outlined it is possible to compare the results, in order to highlight the differences that appear by stretching the regulator policies to the maximum.
The comparison will serve for two main goals:

- Understand the lacks in regulation acknowledging the spots where the regulation is too weak and the discrepancies with company practices.
- Understand where the gap between company performances and the regulation allowed performances are located, to see how virtuous a company is and where possible further increase in performances can be made.

Both serve a purpose, while the former might suit the policymakers helping them understand where to increase strictness of policies to decrease the gap between policies and practices, the latter is a demonstration of how virtuous a company is with respect to the regulation requirements.
The negative value that the tables are showing are related to the decrease in emissions brought by Company performances are to be intended as a positive performance by the Company with respect to the regulator requirements.

3.4.4.1 Pre-localization emission comparison

The first comparison presented is relative to the yearly differences in maximum allowed estimated emissions during the phases that characterize the time before the localization of a leak, calculated subtracting the maximum allowed emission estimates with the current performances that the Company scores by inspecting its network with a higher frequency with respect to the regulator's minimums.

Pre-localization methane emission comparison m^3			
Years	TPN	CSI	Total
2018	-260.824,56	-1.174.715,36	-1.435.539,92
2019	-250.658,43	-1.667.069,61	-1.917.728,04
2020	-275.383,63	-1.492.344,04	-1.767.727,67
2021	-308.794,16	-1.610.432,59	-1.919.226,74
2022	-264.520,43	-1.824.922,89	-2.089.443,32
Total	-1.360.181,21	-7.769.484,49	-9.129.665,70

Notes: Estimation derived from the difference between Company performances and the estimations that resulted using the minimum frequency of inspection allied by the regulator related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by pre-localization method: Third party notified (TPN) and company scheduled inspections (CSI)

Table 30 *Comparison in pre-localization estimated emissions*

The analysis grants the possibility to understand the gap in emissions for what regards the difference in inspection rate, and the decrease in estimated emissions that the Company is able to secure by having a higher inspection rate.

Pre-localization methane emission comparison m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	-21.388,48	-6.028,97	-442.411,28	-965.711,20	-1.435.539,92
2019	-15.285,78	-4.599,89	-587.582,42	-1.310.259,96	-1.917.728,04
2020	-33.889,06	-4.236,13	-605.521,91	-1.124.080,57	-1.767.727,67
2021	-58.571,18	-2.473,18	-572.442,97	-1.285.739,42	-1.919.226,74
2022	-32.340,84	-2.594,19	-660.306,63	-1.394.201,66	-2.089.443,32
Total	-161.475,33	-19.932,35	-2.868.265,21	-6.079.992,80	-9.129.665,70

Notes: Estimation derived from the difference between Company performances and the estimations that resulted using the minimum frequency of inspection allied by the regulator related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 31 *Comparison pre-localization estimated emissions*

The comparisons show an overall decrease of almost 10 million cubic meter of methane emitted over the five years taken into account.

The comparison keeps the trends seen in the previous analysis with company scheduled emissions, those that mostly have been affected by the changes, scoring the higher difference.

When moving to table 31 the differences steeply increase for underground leaks, with pipeline leaks that steadily score differences value over the million cubic meter of methane every year.

3.4.4.2 Post-localization emission comparison

The existence time is the time factor changing during post-localization analysis is the scheduling time of emission elimination, meaning that the changes will effect the leaks depending of their priority.

Post-localization methane emission comparison m³					
Years	A1	A2	B	C	Total
2018	-2.001,26	-3.423,78	-18.867,88	-448.732,36	-473.025,28
2019	-1.969,35	-4.129,42	-31.845,27	-461.523,03	-499.467,06
2020	-2.038,33	-3.641,40	-21.775,30	-555.688,00	-583.143,02
2021	-2.421,64	-2.703,27	-27.803,04	-544.646,28	-577.574,22
2022	-2.242,84	-3.496,04	-26.538,79	-450.141,22	-482.418,90
Total	-10.673,42	-17.393,90	-126.830,28	-2.460.730,88	-2.615.628,48

Notes: Estimation derived from the difference between Company performances and the estimations given by the maximum amount of time given to leak elimination by the regulator related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by priority classes: Immediate priority (A1), High priority (A2), Medium priority (B) and low priority (C).

Table 32 *Comparison post-localization estimated emissions*

As it could've been expected the main differences arise on C prioritized leaks, which result to have the higher gap between Company performances and the Italian regulators allowed time, while for other leak priorities the difference is minimum, with both As scoring a total 5 years difference lower than 20.000 cubic meters.

Post-localization methane emission comparison m³					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	-110.187,84	-32.496,59	-117.014,67	-213.326,19	-473.025,28
2019	-103.261,21	-25.529,41	-143.201,71	-227.474,72	-499.467,06
2020	-120.234,41	-23.485,36	-176.600,04	-262.823,21	-583.143,02
2021	-152.183,63	-20.642,15	-146.765,28	-257.983,15	-577.574,22
2022	-147.450,94	-15.800,90	-121.396,02	-197.771,04	-482.418,90
Total	-633.318,04	-117.954,42	-704.977,71	-1.159.378,31	-2.615.628,48

Notes: Estimation derived from the difference between Company performances and the and the estimations given by the maximum amount of time given to leak elimination by the regulator related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 33 *Comparison post-localization estimated emissions*

The comparison shows an overall decrease in emissions derived by the virtuous company performances of more then 2,5 million cubic meter of methane estimated to be emitting.

As it could be expected the values scale with the priority decrease showing how the vast majority of emissions would come from class C leaks that, from regulator standpoint, are allowed to be kept open for a much higher time, resulting in a decrease of little less than 2,5 million cubic meter of methane emitted given by the higher performances scored by the company with respect to the maximum allowed elimination time given by the regulator.

3.4.4.3 Total emission comparison

Summing up all the comparisons it can be obtained the total differences arising from the comparison where it can be seen that the changes in pre-localization time scores the higher relative amount.

Overall comparison			
Years	**Difference**	**% Incubation**	**% Elimination**
2018	-1.908.565,21	75,22%	24,78%
2019	-2.417.195,10	79,34%	20,66%
2020	-2.350.870,69	75,19%	24,81%
2021	-2.496.800,96	76,87%	23,13%
2022	-2.571.862,22	81,24%	18,76%
Total	-11.745.294,18	77,73%	22,27%

Notes: Total comparison of the estimated emissions performances highlighting the differences in overall emissions as well as the share percentage of each main phase of leak existence

Table 34 *Comparison overall estimated emissions*

The comparison gives us a overview of the differences that arise when the Company performances are compared with the performances that would have been allowed by the regulator when applied the minimum inspection frequency and the maximum allowed elimination time.

Company performances see themselves decrease the amount of cubic meter of methane estimated to be emitted by almost 12 million over the five-year time span that has been analyzed with a yearly decrease with respect to the regulation performances that ranges between 2 and 2,5 million cubic meter of methane.

The higher impact on the difference is given by the incubation period, that accounts steadily over 75% of the total difference, showing great company performances for what regards the inspection of the network.

Such results exhibits the lack of stringency of the Italian regulation as well as the environmental losses that are resulting from them, highlighting the impact of incubation time over the total difference, resulting in further evidence of the importance in quick leak detection for environmental purposes.

Chapter 4 - Mitigation strategies in leak repair

4.1 Prioritizing environmental externalities in leak repair

The current repair priority for leak elimination follows a risk-based approach, the higher the risk the leak poses to the society, the higher the priority of its elimination.
Distribution companies then schedule elimination procedures depending on the priority associated to the leak, prioritizing those that are estimated to be the most dangerous for citizens and the society.
In order to do so the regulator developed a framework able to guide companies in the quantification of the risk, serving as a guideline for leak elimination.
While safety risks are well outlined by the framework the environmental impact of leaks is missing, leaving no trace of a guide helping companies with the establishment of the environmental prioritization of a leak.
How could a leak be classified for its environmental risk? What would be the leaks that result being the most dangerous from an environmental perspective?
If companies were to adapt their leak elimination priority based on the environmental damage potential of a leak, and what would change, in terms of environmental abatement if leaks were to be eliminated for their climate change potential?
Is it possible to combine a safety-based prioritization framework with environmental risk and how this would translate into emissions estimates?
The following chapters examine such questions, assessing a new prioritization methodology that takes into account various factors connected with the environmental impact of a leak, enabling distribution companies to differently prioritize leaks based on their climate change potential, prioritizing those that are estimated to be the most dangerous.
In order to do so, at first a new prioritization technique has been developed, shown in paragraph 4.1.1, with an equation that takes into account: operating pressure, pre-localization method, emission factors and efficiency in repair.
The equation will create a new priority ranking for the leaks, organizing them from the most environmentally dangerous to the least.
Such ranking will then be used to reorganize the prioritization classes following two different models.
The first model, shown in paragraph 4.1.2 will be reorganizing leaks keeping the budget constant, in order to analyze the response in terms of emissions if the Company was to follow the new environmental prioritization.
The second model, in paragraph 4.1.3 follows the first one by adding a safety constraint related to safety, that will be performed by adding a safety constraint and keeping those that are currently classified as immediate priority leaks constant to examine the results in terms of estimated emissions.
The chapter closes with end considerations about the results and the outline of following steps to further analyse mitigation strategies.

4.1.1 Prioritizing emissions

As mentioned before in the document, the current prioritization of leak elimination procedures is based on the physical threats posed by leaks, particularly the risk of the creation of an explosive mix in confined spaces, as methane, having a lower flammable point (LFL) of 3,5%, can ignite easily. Therefore, leaks in which gas can easily accumulate to create explosive mixtures are given immediate attention and are prioritized for elimination within a maximum of 24 hours.
In contrast, leaks that do not present a direct public threat are assigned lower priority, with elimination timings based on their potential danger. Leaks that could become future hazards and are located near fixtures or cavities receive high priority; leaks that pose no immediate threat but are close to fixtures or cavities are given medium priority; and leaks that are no threat due to their location in open air receive low priority, with a maximum elimination timeframe of 180 days.
This prioritization lacks consideration for external impacts, failing to account for the potential environmental effects of leaks, and does not address the emissions they generate, leaving environmentally impactful leaks unaddressed, increasing the volume of methane released, as it leads to an extension in the duration for which methane emissions can accumulate in the atmosphere.
Currently, the regulator establishes four priority classes related to the threat every leak has when located, from the most dangerous to the least dangerous.
The classes are:

- A1: immediate priority, must be eliminated in 24 hours.
- A2: high priority, must be eliminated in 7 days.
- B: medium priority, must be eliminated in 30 days.
- C: low priority, must be eliminated in 180 days.

The source does not influence the prioritization of leaks but indicates where the leak is located relatively to the ground, dividing the leaks in aboveground leaks, underground leaks, and gas meter leaks, all of three presenting different characteristics that influence their importance.
The aim of the document is to interiorize environmental threats that arise from fugitive emissions by adding to the prioritization methodologies factors related to the environmental impact of leaks.
The new prioritization will be performed under two different constraints that reflect a budget constraint and a safety constraint: the budget constraint will represent the zero-cost of the policy idea and it will expressed by keeping both the number of leaks and the amount of operators repairing working-hours constant, while the safety constraint will be added later on and expressed by keeping the number of leaks that are currently classified as immediate priority as constant in order to express the legal requirement to which distribution companies are obliged to.
The two models will be focussing only on changes on the scheduling phase of a leak’s existence, since for a decrease in repair time to be achievable, an increase in investments is required.
The aim is to understand if and how the overall emissions could decrease when the leaks are treated, prioritizing their environmental impact as well as their physical threat.
Since the existence of the leak that is examined in the paragraph is related to the elimination time of a leak, the analysis will focus on post-localization time, which has been expressed before in the document, see chapter 3.4.2.2, it is useful to get back to the time values related to both scheduling and repair time.
The estimation of the scheduling time for every source in every priority class is estimated as the average elimination time for the 5 year time span analyzed, minus the average time estimated to be required by the company to repair such leaks.
The source of the leak, on the other hand, is related to the repair time which does not change in relation to the different priority classes, but depending on the location of the leak.

Leaks that happen above the ground have a shorter repair time given by the easier accessibility and by the smaller complexity of leak repair operation, while on the other hand underground leaks present a higher value expressing the difficulties related to operating under the level of the surface.
Repair time is estimated to be equal to the time that the company spends repairing immediate priority leaks, that supposedly have no scheduling time other than the time needed to gather the operation team and drive to the leak location, that is the reason why the repair time is estimated to be the same for every priority class.
Table 35 presents the current overview of scheduling time[97], repair time[98] and elimination time for the post-localization existence of leaks, dividing the number of leaks in just priority classes and sources as those are the two variables that have effect on the choice and the estimation of the factors related to the time.

	Priority	**Source**	**Leaks number**	**Scheduling time (h)**	**Repair time (h)**	**Elimination time (h)**
Current leak elimination overview	Immediate priority (A1)	Aboveground	6.484	1,0	0,5	1,5
		Pipelines	955	1,0	4,6	5,64
		Components	1.132	1,0	4,6	5,56
		Gas meter	5.078	1,0	0,4	1,4
	High priority (A2)	Aboveground	59	25,7	0,5	26,2
		Pipelines	592	58,9	4,6	63,5
		Components	227	70,5	4,6	75,11
	Medium priority (B)	Aboveground	40	96,7	0,5	97,2
		Pipelines	1313	383,7	4,6	388,4
		Components	440	333,8	4,6	338,4
	Low priority (C)	Aboveground	16.478	149,6	0,5	150,1
		Pipelines	1478	962,8	4,6	967,4
		Components	931	974,9	4,6	979,5
		Gas meter	5.923	7,7	0,4	8,1

Notes: In order: Priority classes divided in A1, A2, B and C; source of the emission, divided in aboveground, underground pipelines, underground components and gas meters; leak number relatively to the priority class and the source; scheduling time expressed in hours depending on the priority class and the source; the repair time, expressed in hours, relative to the source of the leak; the elimination time as the sum of the scheduling time and the repair time, expressed in hours.
All time values are exhibited as the average of the yearly values, for the years from 2018 to 2022.

Table 35 *Current leak elimination time overview*

Repairing time is the main time variable that serves our purposes since it is the time variable that is directly correlated with the time spent on leak repairing procedures and it is independent from the priority class of the leak, from which the scheme has the aim to differentiate.

[97] Annex III.II Tab XXV - XXVIII
[98] Annex III.II Tab XXIX - XXXII

The repair time for underground sources in the model will be supposed to be the same (4,6 h) since the average five year values for both pipelines and components end up being very similar, and the pairing helps with the prioritization that will be performed later on in the document.
In order to better suit the variable for the index it is important to understand the relation between the emission factor and the repair time, in order for the variable to show the reparation efficiency when looking at methane emissions.
This value expresses the return for unit of time investment (RUTI), and shows the amount of natural gas reduced every hour invested by the company in repairing operations and is expressed in scm/h^2.
To better suit the variable for index, it is important to understand the relation between the emission factor[99] and the repair time, which is expressed through the return for unit of time investment (RUTI). This value, expressed in scm/h^2, shows the amount of natural gas reduced due to every hour invested by the company in repairing operation and presents the reparation efficiency when looking at methane emissions.
This value is the result of the following equation:

$$RUTI = \frac{Emission\ factor}{Repair\ time}$$

Source	Leak number	Repair time (h)	Emission factor (scm/h)	RUTI
Aboveground	23.061	0,5	0,01	0,02
Underground	7.238	4,6	0,24	0,05
Gas meter	11.001	0,4	0,005	0,01

Notes: For every source the table shows the respective leak number, repair time needed expressed in hours, the emission factor in standard cubic meter of natural gas leaked every hour and the RUTI value.

Table 36 *Return for unit of time invested*

The value is useful to understand which leak repairing procedures generate the most returns for each hour the company invests repairing leaks of that precise source, resulting in a factor that is capable of expressing the efficiency of leak repair operations, hence which leaks, if repaired, decrease at a higher amount the level of emissions that they produced.
Leaks sourced underground show more efficiency for what regards the repair, requiring a lesser amount of time to achieve higher emission abatement volumes.
On the other hand, aboveground leaks, while having a short repair time, pay the price of having a smaller emission factor, as well as gas meters that are even less efficient.
This analysis helps to understand which leaking sources have potential for optimization, allowing emission abatement with the least amount of time spent in repairing processes.
The other component of the analysis are the emissions and their relation with respect to the separate sources which will be integrated with both the operating pressure, and the pre-localization method, crossed with the current priority, grants a broad idea on the location of the specific leak emission factor location around the averages that are used in this document for estimation purposes.
The operating pressure will be internalized by looking at the differences between the emission factor of steel pipelines that is included in the ISPRA technical documents, such factors have been chosen

[99] Annex III, Tab. XVI

due to the high share of the network[100] made out of steel as it is also the only material that has part of the network both in medium and low pressure, high pressure emission factor will be ignored since the share of high pressure operated network is negligible.
The values that are used to calculate the differences in emissions between medium pressure network leaks and low pressure network leaks are the following:

- Medium pressure EF: 319,90 scm/h
- Low pressure EF: 207,50 scm/h

Since the data do not show the pressure of the network of which the source is part of, the estimation of the number of leaks belonging to a certain pressured network has been made following the assumption that leaks appear on the network following a normal distribution, equally distributing all over the network, ignoring the differences in territories and soils in which the pipeline and the underground components are posed.
While this is a very stretched assumption, without having a clear mapping of the distribution network, that would need of a leak mapping and data that as of now are not in possession, this looks like the best possibility to at least get a magnitude of the problem, knowing that further analysis are needed to reach more precise prioritization.
In order to equally spread all pipeline leaks and underground components to the different pressure network, the share of each pressure possibility has been calculated:

Pressure	Network length (Km)	Share of operating pressure (%)	Number of leaks	
			Pipeline	Components
Medium	8.962,89	61,99%	2.950	1.972
Low	5.496,00	38,01%	1.388	928
Total	14.458,89	100,00%	4.388	2.900

Notes: The table shows for every operating pressures, the length of the network operated in such way, the share of the network operated in such pressure over the total network length and the number of leaks registered normally estimated by pressure.

Table 37 *Operating pressure*

In order to build an effective modifier that expresses the differences in emission factor depending on the operating pressure, the values have been normalized with respect to a reference value that has been chosen to be the low pressure emission factor.
Operating pressure (OP) modifier

- Medium pressure (MP) modifier factor:
  $$MPm = \frac{Medium\ pressure\ EF}{Low\ pressure\ EF} = \frac{319,90}{207,50} = 1,54$$

- Low pressure (LP) modifier factor:
  $$LPm = \frac{Low\ pressure\ EF}{Low\ pressure\ EF} = 1,00$$

[100] Annex I - Tab I

As expected from the base values the medium pressure modifier has a higher value, showing the higher impact of the increased operating pressure, while for low pressure operated network leaks the value stays 1 and it is treated as reference value.
The second modifier as aforementioned will be focusing on the pre-localization method.
The assumption behind this idea, backed up by the company's technical guidelines and experts' opinion, is that third-party notified leaks have on average a higher volumetric flow of natural gas due to the possibility to feel their presence through smell and hearing.
Since such leaks are noticed by odorization, their flow has to be a sufficient amount in order for the gas to spread in the environment, overtaking the olfactive detectable natural gas volume percentage threshold, that is commonly estimated to be 1%, 1/5 of the lower flammable level, showing generally considerably higher emissions with respect to the average leak since small leaks tend to dissolve in the environment being of difficult perception, only detectable by sensors.
These leaks are then supposedly immediately notified, meaning their possible association with dangerous situations or significant emitting flows.
On the other hand leaks that are discovered during company inspections are detected using specific tools and sensors that are made in order to find smaller leaks that are not easy to be located through odorization, and have often the goal to intercept leaks before they become significant, hence, by definition, inspections might capture leaks with a lower emission factor with respect to those felt by olfactory means.
In order to internalize this difference into the prioritization algorithm it has been supposed that on average, based on the previous assumptions, leaks notified by third parties are located in the upper half of the emission factor values, while leaks pre-localized during schedule inspections made by the company are supposed to be located, on the other hand, in the lower half.
To express such difference, the third party notified leaks (TPN) have been granted a modifier of +25% with respect to their source-specific average value for emission factor, while to inspected leaks the modifier value equals -25% with respect to their average source-specific value for emission factor.
The reason behind the choice to use a modifier value based on the concept of quartiles (+25% or -25%) is a simple and intuitive method to differentiate the two pre-localization methods based on their assumed position in the emission factor distribution. The simplicity of the choice has some disadvantages, as other options based on specific data and more refined theories might be more precise.
The choice of 25% values directly linked to the concept of quartile, implying that leaks pre-localized after the notification of third parties are part to the higher range, 75° percentile, while those pre-localized during company inspections belong to the lower range, 25° percentile, this method favors simplicity as it grants a quick differentiation with a small amount of data. As mentioned before, the downsides are the generalization of the assumptions since it could not reflect the real distribution of the data, hence producing rough estimates, but given the lack of data a rough estimate is enough to understand the impact of the differences in pre-localization methods.
After all consideration, quartile values are supposedly good enough to grant a rough idea of pre-localization effect and the following values are used for environmental priority valuation.
Pre-localization (PLm) modifier:

- Third-party notified (*TPN*) modifier:
  $TP\,Nm = 1 + 0,25 = 1,25$
- Company's schedule inspection (*CSI*) modifier:
  $CSIm = 1 - 0,25 = 0,75$

The number of leaks with respect to their pre-localization method is determined by the data in possession of the company, and considering that all leak elimination reports mention the method of pre-localization, this data is deemed to be as certain as it could be.

Source	Pre-localization method	Leaks number	Percentage share
Aboveground	TN	19.766,00	47,86%
	CSI	3.295,00	7,98%
Underground	TN	2.151,00	5,21%
	CSI	5.087,00	12,32%
Gas meter	TN	9.976,00	24,15%
	CSI	1.025,00	2,48%
	TN	31.893,00	77,22%
	CSI	9.407,00	22,78%
Total	Total	41.300,00	100,00%

Notes: The table divides every source divided by Third-party notified (TPN) leaks and leaks found during company scheduled inspections (CSI) exhibiting the number of leaks belonging to that group and the share percentage over the total of leaks eliminated by the company over the years examined (2018-2022)

Table 38 *Pre-localization method numbers*

Once all modifiers are set in place is time to develop a complete equation for leak prioritization based solely on their environmental impact:

$$P = EF * OPm * Plm * RUTI * 100 \quad (1)$$

Where:

- P is the priority value
- EF is the emission factor, variable depending on the source of the leak.
- OPm is the Operative pressure modifier, variable depending on the operating pressure running the network.
- PLm is the Pre-localization method modifier, variable depending on the pre-localization method used to pre-localize the leak
- RUTI is the return for unit time invested, variable depending on the relation between the emission factor and the repairing time of a leak.
- 100 is an arbitrary value with the only objective to increase the values in order to grant simplicity of reading

The values expressed show some interesting, as well as expected, results.
For what was clear from the different variable designs, leaks with a higher emission value are favored, the RUTI value favors the same trend of the emission factor, since the leaks with the highest emission factor show the higher RUTI.
Another predictable aspect is the similar values shared by the four P variables for pipeline and components. Since underground leaks tend to consistently produce nearly identical values for the variables, this results in comparable values for P. As a consequence, pipelines' and components'

sources are incorporated in a singular source named “Underground”; this grouping is favored because even with a minor difference in the RUTI, following calculation and operative procedures are not affected.
The low level of *P* for aboveground leaks reflects their small importance in terms of natural gas fugitive leaks that are eventually followed by gas meter leaks that present the lowest possible values.

Source	***P***	**Pre-localization value**	**Operating pressure value**	**Emission factor (scm/h)**	**RUTI (scm/h2)**
	0,027	1,25			
Aboveground	0,016	0,75	1,00	0,01	0,02
	1,565	1,25			
	0,939	0,75	1,00		
	2,410	1,25			
Underground	1,446	0,75	1,54	0,24	0,05
	0,008	1,25			
Gas meter	0,005	0,75	1,00	0,005	0,01

Notes: The table resumes all the values for the factors used for the prioritization using the P formula by source, The value of P is showed in the first columns related to every Pre-localization method fro every source, second columns the pre-localization value, the operating pressure factor, the emission factor expressed in standard cubic meters of natural gas emitted every hour and the RUTI factor value

Table 39 *Values of P and variables involved*

Once every leak category has been prioritized by the proposed methodology, the categories are hierarchically ordered with the groups with the highest priority (*P*) at the top of the rankings as displayed in tab 40.

Source	**Operating pressure**	**Pre-localization**	**Leak number**
Underground	MP	TPN	1.333
	LP	TPN	818
	MP	CSI	3.153
	LP	CSI	1.934
Aboveground	LP	TPN	19.766
		CSI	3.295
Gas meter	LP	TPN	9.976
		CSI	1.025

Notes: Priority rankings developed by the implementation of equation P divided by source, operating pressure, pre-localization method and the respective number of leaks interested.

***Table 40** Leak elimination priority rankings.*

For all sources, third party notified (TPN) leaks rank first priority-wise, as underground leaks of both pressure values score a higher *P* than leaks pre-localized by the company (CSI), which rank second in the priority classification.
Following, as mentioned previously, aboveground and gas meter leaks with those pre-localized by third-party notification on top of the relative source.

4.1.2 Budget constraint model

To establish a budget constraint aligned with the objectives of this document, two main factors are considered: the repair time required to fix leaks from each source and the number of leaks within each priority class. This constraint ensures that proposed changes in leak prioritization do not increase the costs associated with leak elimination for the Company.
The repair time for each leak source serves as the baseline, representing the amount of time the company needs to dedicate to repairing leaks from a specific source. This baseline is then multiplied by the number of leaks for that particular source to estimate the total repair time required for that category. The workload budget ensures that the variable costs for leak repairs are kept constant which in the document are associated with the variable costs related to the time needed to repair a certain leak.
The final step involves summing the repair hours across all priority classes to calculate the total operating time spent by the company's personnel on leak repair tasks. This comprehensive analysis provides a clear overview of the time allocation across different priority classes, ensuring that the distribution of resources aligns with operational constraints.

	Priority	Source	Leaks number	Repair time (h)	Personnel workload (h)	Priority budget (h)	Share percentage
Current time budget overview	Immediate priority (A1)	Aboveground	6.484	0,5	3.047,48	15.351,42	31,78%
		Pipelines	955	4,6	5.990,50		
		Components	1.302	4,6	4.393,96		
		Gas meter	5.078	0,4	1.919,48		
	High priority (A2)	Aboveground	59	0,5	27,73	3.795,95	7,86%
		Pipelines	592	4,6	1.044,43		
		Components	227	4,6	2.723,79		
	Medium priority (B)	Aboveground	40	0,5	18,80	8.084,35	16,74%
		Pipelines	1.313	4,6	2.024,44		
		Components	440	4,6	6.041,11		
	Low priority (C)	Aboveground	16.478	0,5	7.744,66	21.067,36	43,62%
		Pipelines	1.478	4,6	2.238,89		
		Components	931	4,6	4.283,53		
		Gas meter	5.923	0,4	6.800,28		
Total	All	All	41.300		48.299,09	48.299,09	100%

Notes: The table shows how the current time budget is formed, dividing every priority class in sources and exhibiting the number of leaks related to every source for every priority, with the relative repair time and the personnel workload dedicated, which is calculated with equation (1), the last two columns show the priority budget expressed in hours and the share of such budget over the total of workload hours.

Table 41 *Current time budget overview*

The table provides an overview of the time budget allocation in terms of hours of work required to repair methane leaks, broken down by priority and leak source.

The last three columns are particularly important for understanding the operational impact and the distribution of company resources since they express the personnel workload for every source in every priority class and the total workload associated with every priority class.

Personnel workload column is the result of the multiplication between the number of leaks and the repair time:

$$Personnel\,workload = \sum_{sources} Leaks \; * \; repair\ time \qquad (2)$$

Such time value indicates the total workload, measured in hours, required to repair all leaks within a specific combination of priority and source.

Priority budget represents the sum of the hours required for each specific priority level, across all associated sources. It provides an aggregate measure of the time allocated to each priority class, offering insights into the overall commitment of resources. It helps determine whether resource allocation aligns with the expected impact of leaks in terms of emissions or risk.

The share percentage column shows the proportion of total time dedicated to each priority class, expressed as a percentage of the company's total workload. It is a key indicator for evaluating the effectiveness of resource distribution and verifying if operational focus reflects the company's strategic goals, such as reducing high-impact leaks.

Immediate priority (A1) accounts for 31,78% of the total time, highlighting a significant focus on addressing critical leaks. This is aligned with the objective of rapidly mitigating high-impact or high-risk leaks. High priority (A2) receives 7,86% of the resources, a proportion that might require further evaluation to determine if it is sufficient relative to the potential impact of leaks in this category.

Medium priority (B) and low priority (C) consume 16,74% and 43,62% of the total time, respectively. While low-priority leaks represent the largest share of allocated hours, it may be useful to assess whether this reflects an optimal strategy for reducing overall emissions.

Once the budget has been outlined, there are two possible approaches for developing a budget constraint:

- Using the budget for each priority class, allocating a coherent and strict budget based on the current workload expenses and prioritization scheme. It ensures that resources are distributed in accordance with the existing allocation model.
- Equally splitting the total budget across all priority classes as the total available budget is divided equally among the priority classes, leading to a reallocation of resources that may require adjustments to the current workload management strategies.

	Immediate priority	**High priority**	**Medium priority**	**Low priority**
Current priority budget (h)	15.351,42	3.795,95	8.084,35	21.067,36

Equally split workload (h)	12.074,77	12.074,77	12.074,77	12.074,77

Notes: The table shows how the current time budget could be allocated showing in the first row the current time budget divided by priorities as it is right now and on the second row an allocation that does not follow the current allocation but equally splits the workload from the total workload

Table 42 *Time budget allocation*

While equally splitting the total budget may seem like a fairer approach in terms of resource distribution, it would weaken the original budgeting structure. The current priority-based method allows for a more strategic allocation of resources, ensuring that the most critical tasks are addressed first and that resources are used efficiently. Dividing the budget equally across all priority classes would reduce the effectiveness of this approach by overlooking the differences in workload and urgency between the classes.

Therefore, sticking with the current priority-based allocation is crucial for maintaining a coherent and impactful budgeting strategy, creating a constraint that stays close to the current reality of workload allocations.

It is also true that anchoring to the actual budget would make the scheme susceptible to the actual prioritization scheme decreasing the degrees of freedom within which it is possible to develop a new priority scheme.

Worth to acknowledge and remember is that the main driver of priority class budget is the type of leaks identified by the company; these leaks are not strategically planned or chosen by the company, but rather determined by the inherent danger of the leaks that occur.

In order to give monetary values to the workload budget, the personnel cost for leak repair has been divided by the total hours that are spent repairing leaks, resulting in a hourly costs for leak repair of 333,78 € that is equal for every leak since the cost of personnel does not change with respect to the different leak source.

Personnel cost	€ 16.140.934,80
Total workload (h)	48.299,09
Hourly cost	€ 334,19

Notes: The table shows the personnel costs that the company has for leak repair procedures, the total workload that the Company operators spend by working on the leak repair and the hourly cost of leak repair procedures

Table 43 *Leak repair costs*

Introducing the monetary budget as a mean to constrain the model aims to maintain the costs the Company faces for leak repairing as constant as possible and forces the analysis to take into account the effort the Company already makes for leak repairing. This objective is due to the fact it would be too simplistic of a solution to propose speedier leak repairs, which would also mean asking the Company to increase the investments dedicated to leak repair procedures.

The priority class time budget is then multiplied by the costs for one hour of leak repair personnel work resulting in those that will be the monetary budget classes from where the new prioritization classes will be built upon.

A1	A2	B	C	Personnel cost
€ 5.130.247,92	€ 1.268.557,45	€ 2.701.687,04	€ 7.040.442,39	€ 16.140.934,80

Notes: The table shows the monetary budget the company allocates for every leak priority class in Euros, dividing the budgeting in priority classes and with the last column exhibiting the total costs that are kept equal to the total personnel costs

Table 44 *Monetary budgeting*

Table 44 shows how the working time budget translates into monetary terms.
It can be noticed the same trends that have been shown before, with A1 and C classes taking the most of the budget while A2 and B classes, due to the low number of leaks, follow distantly. The monetary budget will aid the following analysis in which leaks, once reprioritized with *P,* will be reorganized using the budget constraint for class formation. The classes will be filled from highest to lowest priority, placing leaks into a specific class until the budget allocated for that class is exhausted; afterwards moving to the following class, until all leaks have been reclassified.
Once the reorganizing procedure is completed, the analysis will continue with a new post-localization emission estimation, eventually crowning the model with an emission comparison between the current post-localization emissions and the one that comes out of the new prioritization.

4.1.2.1 New priority classes

Leak reclassification is the key step in order to understand how the new environmental based prioritization will impact leak repair priorities and how the new classes will be composed.
Once the leak prioritization process is finalized with the rankings exhibited in table 6 it is possible to establish new leak repair priority classes by crossing the leak priority with the budget constraint estimated earlier in the document.

	Immediate priority	**High priority**	**Medium priority**	**Low priority**
Time budget (h)	15.351,42	3.795,95	8.084,35	21.067,36
Monetary budget	€5.130.247,92	€1.268.557,45	€2.701.687,04	€7.040.442,39

Notes: The table shows the monetary budget the company allocates for every leak priority class in Euros, and the relative time budget from which the monetary budget has been calculated from, dividing the budgeting in priority classes and with the last column exhibiting the total costs that are kept equal to the total personnel costs

Table 45 *Monetary and time budgeting*

Table 45 harks back to table 42 and 44 showing the time budget chosen for budget allocation and the relative monetary budget allocation.
The budget will be used to establish the priority classes following the new priority rankings, while the class budget values will serve as thresholds that are progressively filled by handling first the leaks with the highest priority given by the value of P.
In order to accurately fill the monetary budget, the cost of each leak will be used as a filling value, ensuring a precise number of leaks for every new class. This approach gives more robustness and realism to the new classification, because using time costs would lead to percentages of leaks being distributed in between classes, which would be impossible for operative repair.
The different sources used for the model are divided by their overall cost of repair, estimated by multiplying the hourly cost for the amount of overall time dedicated to repair leaks of that particular source.

$$Overall\ source\ repairing\ cost\ =\ hourly\ leak\ repair\ cost\ *\ overall\ source\ repairing\ hours$$

Source	**Hourly cost (€)**	**Overall repair time (h)**	**Overall repair cost (€)**
Aboveground	€ 334,19	10.838,67	€3.622.144,44
Gas meters		4.158,38	€1.389.676,57
Underground		33.302,04	€11.129.113,79
Total		48.299,09	€16.140.934,80

Notes: The table shows for the different leak sources the common hourly personnel cost, the specific overall repair time dedicated to repair leaks belonging to the specific source and the result of their multiplication expressing the overall repair cost for each leaking source.

Table 46 *Overall repair costs*

Then, by using the specific number of leaks belonging to each source, the cost per leak for every specific source has been calculated. These values will be used to reorganize the different priority classes by filling the current priority class monetary budgets.

$$Cost\ per\ leak\ =\ overall\ source\ repairing\ cost/\ source\ leak\ number$$

The result of the division is exhibited in table 47.

Source	Overall repair cost (€)	Leak number	Cost per leak (€)
Aboveground	€ 3.622.144,44	23.061	€ 157,07
Gas meters	€ 1.389.676,57	11.001	€ 126,32
Underground	€ 11.129.113,79	7.238	€ 1.537,60
Total	€ 16.140.934,80	41.300	

Notes: The table shows for the different leak sources, the specific overall repair cost allocated by the Company, expressed in euros, the number of leaks belonging to the specific source and the result of their division expressing the specific cost per leak repaired for each leaking source, expressed in euros.

Table 47 *Cost per leak*

Since the class budget was outlined by using the time value to account for different sources of leak repair, the filling by number of leaks may not be completely precise, leaving gaps between the number of reorganized leaks and the budget set for every class. To address this, the budgets have been respected by maximizing the number of leaks without exceeding the budget thresholds for the immediate, high and medium priority classes; only when it came to the low priority class the budget was surpassed. By doing so, the integrity of the overall budget as well as that of the aforementioned classes have been respected by pushing down leak repair, eventually resulting in a higher cost for low priority repairs that exceeds the relative threshold.

Source	Operating pressure	Pre localization	Leak number	Leak repair cost (€)	Total repair cost (€)	Cumulative costs (€)	Budget model priorities	Class budget (€)
Under ground	MP	TPN	1.333	€ 1.538	€ 2.049.614	€ 2.049.614	Immediate priority	
	LP	TPN	818		€ 1.257.753	€ 3.307.367		
	MP	CSI	1.185		€ 1.822.050	**€ 5.129.417**		€ 5.130.248
			825		€ 1.268.516	**€ 1.268.516**	High priority	€ 1.268.557
			1.143		€ 1.757.471	€ 1.757.471	Medium priority	
	LP	CSI	614		€ 944.083	**€ 2.701.555**		€ 2.701.687
			1.320		€ 2.029.626	€ 2.029.626	Low priority	
Above ground	LP	TPN	19.766	€ 157	€ 3.104.605	€ 5.134.231		
		CSI	3.295		€ 517.539	€ 5.651.770		
Gas meter	LP	TPN	9.976	€ 126	€ 1.260.196	€ 6.911.966		
		CSI	1.025		€ 129.481	**€ 7.041.447**		€ 7.040.442
Total			41.300		€ 16.140.935	€ 16.140.935		€ 16.140.935

Notes: The table exhibits the number of leaks that for every operating pressure and pre-localization method fill the new priority classes by showing their number, the relative source leak repair cost, expressed in euros, the total repair cost , expressed in euros, the cumulative costs , expressed in euros, highlighting the values that fill the class budgets, the new priorities of such classes and the budget constraint.

Table 48 *Budget constraint model priority classes reclassification*

The priority classes that result from the reclassification are the following:

Budget model priorities	**Total number**	**Number**	**Source**	**Pressure**	**Pre localization method**
Immediate priority	3.336	1.333	Underground	MP	TPN
		818		LP	TPN
		1.185		MP	CSI
High priority	825	825			
Medium priority	1.757	1.143			
		614		LP	CSI
Low priority	35.382	1.320			
		19.766	Aboveground	LP	TPN
		3.295			CSI
		9.976	Gas meter	LP	TPN
		1.025			CSI

Notes: The table shows how the reclassification results in the new priority classes, diving them by the total number of leak that belong to that priority class, and how that total number is composed specifying the leaks that compose it divided in source, pressure and pre localization method

Table 49 *Budget constraint model priority classes*

With the new priority classes, it is possible to estimate emissions, prioritizing the leaks and giving to emissions abatement the precedence over safety. Moreover, this approach also highlights the possible differences that arise from the change in prioritization.

4.1.2.2 Emission estimation

The estimation of natural gas emissions is based on elimination time, as the new priority classes affect this phase of the leak's existence. The leak priority reclassification furthermore impacts the scheduling time, thus affecting the moments subsequent to leak localization.

$$E = N * t_2 * EF \qquad (2)$$

Where:

- E are the estimated emissions
- N is the number of leaks
- t_2 is the leak elimination time expressed in hours
- EF is the emission factor expressed in standard cubic meters per hour

For estimation purposes, the leaks have been summed up by operating pressure and pre-localization method, in accordance with the groups established earlier in the document.

The current elimination time depends on two main factors: the source and the priority assigned to a certain leak. For the estimation of the total elimination time resulting by the new priority classes, the previous singular elimination time has been collected based off the current elimination time allocated for the specific source and priority, i.e. for the estimation of the new immediate underground leaks, the elimination time currently dedicated to eliminate underground leaks is used and multiplied by the new number of leaks that belong to the new immediate priority class.

$$T_2 = AF = N * t_2$$

The results are exhibited in the table below:

Budget model priorities	Source	Operating pressure	Pre localization	Number	Elimination time (h)	Total elimination time (h)
Immediate priority	Under ground	MP	TPN	1.333	5,60	7.464,80
		LP	TPN	818		4.580,80
		MP	CSI	1.185		6.636,00
High priority				825	69,31	57.176,63
Medium priority				1.143	363,40	415.366,20
		LP	CSI	614		223.127,60
Low priority				1.320	973,45	1.284.954,00
	Above ground	LP	TPN	19.766	150,10	2.966.876,60
			CSI	3.295		494.579,50
	Gas meter	LP	TPN	9.976	8,10	80.805,60
			CSI	1.025		8.302,50
Total				41.300		5.549.870,23

Notes: The table shows how the total elimination time is estimated, diving the results by new priority, emission source, operating pressure and pre-localization method. The new total elimination time, expressed in hours is the result of the multiplication between the current elimination time, expressed in hours and the number of leaks belonging to the new priority classes divided by the factore aforementioned.

***Table 50** Budget constraint model total elimination time*

Once the values for t_2 have been estimated it is possible to follow the time estimation with the emissions estimation by multiplying the total elimination time, that now will be the emission activity factor, for the different source emission factors, showing a different version of equation (2)

$$E = AF * EF \qquad (2)$$

The results are shown in the following table:

Budget model priorities	Source	Operating pressure	Pre localization	Number	Total elimination time (h)	Emission factors (scm/h)	Estimated emissions (scm)
Immediate priority	Under ground	MP	TPN	1.333	7.464,80	0,24	1.791,55
		LP	TPN	818	4.580,80		1.099,39
		MP	CSI	1.185	6.636,00		1.592,64
High priority				825	57.176,63		13.722,39
Medium priority				1.143	415.366,20		99.687,89
		LP	CSI	614	223.127,60		53.550,62
Low priority				1.320	1.284.954,00		308.388,96
	Above ground	LP	TPN	19.766	2.966.876,60	0,01	29.668,77
			CSI	3.295	494.579,50		4.945,80
	Gas meter	LP	TPN	9.976	80.805,60	0,005	404,03
			CSI	1.025	8.302,50		41,51
Total				41.300	5.549.870,23		514.893,55

Notes: The table shows how the emissions related to the priority classes changes are estimated, diving the results by new priority, emission source, operating pressure and pre-localization method. The new estimated emissions, expressed in standard cubic meters of natural gas is the result of the multiplication between the total elimination time, expressed in hours and the emission factors of every source, expressed in standard cubic meter per hours grouped by the factors aforementioned.

Table 51 *Budget constraint model estimated emissions*

The results show a total volume of natural gas emitted of 514.893,55 standard cubic meters (scm) of natural gas that when converted in methane, knowing that the average composition of natural gas in the italian pipeline system is made by 92% of methane, show a result of 473.702,06 m^3 methane emitted, which is equal to 12.789.955,72 m^3 of carbon dioxide equivalent when multiplied by the IPCC global warming potential (GWP) for methane of 29,8.

Natural gas (scm)	514.893
Methane (m^3)	473.702
Carbon dioxide (m^3)	14.116.321

Notes: New estimated emissions expressed by different measure, first row: natural gas estimated emissions expressed in standard cubic meters of natural gas; second row methane estimated emissions expressed in cubic meters of methane (CH_4); third row: carbon dioxide equivalent estimated emissions expressed in cubic meters of carbon dioxide equivalent (CO_2eq)

Table 52 *Budget constraint model estimated emissions*

To have a better comprehension of the changes generated by the reorganization of priority classes it is useful to compare the results of the two schemes relative to emissions.

Natural gas (scm)	757.466
Methane (m^3)	696.869
Carbon dioxide (m^3)	20.766.706

Notes: Current estimated emissions expressed by different measure, first row: natural gas by estimated emissions expressed in standard cubic meters of natural gas; second row methane estimated emissions expressed in cubic meters of methane (CH_4); third row: carbon dioxide equivalent estimated emissions expressed in cubic meters of carbon dioxide equivalent (CO_2eq)

Table 53 *Current estimated emissions*

Now by comparing them it is possible to value in terms of emission differences the changes that are registered by the new priority classification

	New estimated emissions	Current estimated emissions	Emissions difference
Natural gas (scm)	514.893,55	757.466,67	-242.573,12
Methane (m^3)	473.702,06	696.869,34	-223.167,27
Carbon dioxide (m^3)	12.789.955,72	18.815.472,07	-6.025.516,35

Notes: Difference of estimated emissions expressed by different measure, first row: natural gas by estimated emissions expressed in standard cubic meters of natural gas; second row methane estimated emissions expressed in cubic meters of methane (CH_4); third row: carbon dioxide equivalent estimated emissions expressed in cubic meters of carbon dioxide equivalent (CO_2eq)

Table 54 *Budget constraint model estimated emissions difference*

Table 54 shows in its last column the difference in emission estimation between the current emissions, in the second column, and the new emissions, shown in the first column.
The results are positive highlighting a decrease in emissions when the priority changes from a safety-driven prioritization classification to an environmental-driven classification.
The abatement prioritization would decrease the total amount of emissions by more than 30% which can be considered a valid result, especially if it is related also to the decrease in emissions per unit of time worked, which expresses an increase in efficiency in the use of working hours.

Difference (smc)	-242.573,12
Difference %	-32,02%
Emissions per unite time worked	-4

Notes: The table shows the difference in natural gas emission estimation, expressed in standard cubic meters of natural gas, the percentage difference resulting from the changes in prioritization and the difference in emissions per unite time worked, result of the difference between the ration between the total workload and estimated emissions, current and new.

Table 55 *Budget constraint model estimation emissions difference metrics*

4.1.2.3 Benefit analysis

By pricing the emissions abated following the new prioritization it is possible to estimate both the market costs of prevented methane emissions, and the estimated costs for what is the environmental costs of methane emissions, related to their impact on climate change.
Estimating the market price of the natural gas prevented from being emitted into the atmosphere is quite quick and does not require a large amount of data, as the information regarding the natural gas market is easily accessible.
The data used for the estimation is the market price in the Punto di Scambio Virtuale (PSV) the italian wholesale natural gas market managed by the Gestore Servizi Energetici that as of today has a price of 0,45 €/scm[101]. To estimate the environmental externalities and consequent benefits of decreasing methane emissions, the European Union Emission Trading System (EU ETS) price for carbon dioxide allowances has been used; this system is regarded to be the most reliable source for internalizing such externalities.
The cost for a permit allowance for a ton of carbon dioxide, in the EU ETS market, has been valued at 80 €/ton, which has been used as externality price for tons of CO_2eq by expressing the volume of methane in mass of methane, by using a density x_{ch4} of 0,796 kg/m^3[102]:

$$Q_m = Q_v * x_{ch4}$$

From the equation it can be stated that a cubic meter of methane is equal to 0,796 kilograms of methane. Then the CO_2eq mass for 0,796kg of methane has to be calculated with the following formula:

$$CO_2eq_m = Ch_{4\,m} * Ch_{4\,GWP}$$

where the global warming potential (GWP) of methane is equal to 29,8[103].
That results in 22,91 kg of carbon dioxide equivalent at standard condition for every cubic meter of methane.
The cost for one kilogram of CO_2eq is equal to:

$$CO_2eq\ cost = \frac{EU\ ETS}{1000} = \frac{80}{1000} = 0,08€$$

hence the cost for 22,91 kg of carbon dioxide is equal to 1,83€, that by transitive property shows that:

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101 ICIS Heren, 2024
102 DEFRA 2024
103 The global warming potential of methane with respect to carbon dioxide is set to be 29,8 times by the International Panel for Climate Change 6th assessment (IPCC, global warming potential values, version 2.0, August 7th, 2024)

$1\,m^3\,Ch_4 = 0,796\,kg\,Ch_4 = 22,91\,kgCO_2eq \;= 1,83€$

Hence, it is possible to estimate that every cubic meter emitted directly to the atmosphere if priced by using the EU ETS CO_2eq price has a value of 1,83€.

With that being said, it is now possible to develop a complete benefit analysis, since the costs have been kept equal to zero by the budget constraint.

	Unit cost	Emission difference	Benefit
Economic benefit	€ 0,45	242.573	€ 109.157
Environmental benefit	€ 1,83	263.167	€ 481.595

Notes: The table shows the different benefits that arise from the change in prioritization, the first row shows the economic benefits:
first column: the cost per unit expressed in euros per standard cubic meter of natural gas emitted; second column: natural gas emissions abated by the change in prioritization expressed in standard cubic meters of natural gas; the third column economic benefit related to the abated natural gas emissions resulting by the multiplication of the unit cost for the emissions abated. The second row shows the environmental benefits: first column: the unit cost expressed in euros per cubic meter of methane emitted; second column: methane emission abated by the change in prioritization expressed in cubic meters of methane; third column: environmental benefit related to the abated methane emissions resulting from the multiplication of the unit time and the abated methane emissions expressed in euros.

Table 56 *Budget constraint model benefits*

The values expressed in table 56 are the monetary benefits arising from the change that the model brings in priority evaluation.

The economic benefit reflects the abated cost that the decrease in natural gas emissions brings to the market, which is equal to the market cost of the recovered natural gas, while the environmental benefit is intended as the externality connected with the greenhouse gas potential of methane and reflects the abatement of methane in the atmosphere.

The sum of the two reflect the total social benefits that the changes would bring to society.

Economic benefit	**Environmental benefit**	**Social benefit**
€ 109.157	€ 481.595	€ 590.752

Notes: The table shows the different benefits arising from the changes in prioritization of leak repair, expressed in euros.

Table 57 *Budget constraint model benefits*

4.1.3 Budget and safety constraint model

The budget constraint model, although prioritizing environmental externalities, does not take into account the physical risks that natural gas leaks pose to society, failing to ensure safety to end consumers.

Statistically almost every year around 10% of gas distribution accidents present casualties, which can be divided into two different categories: with explosion or fire and without explosion or fire, with the latter being attributed to the consequences of the inhalation of combustion products released in the ambient due to incorrect evacuation and/or due to a lack of oxygen in the room.

The high flammability of the natural gas mixture makes distribution companies the safety guardians of the distribution service, as their first objective is to ensure that the quality and the safety of the service is ensured, as per the Italian law.

The main law relative to the safety[104] of domestic use of natural gas is n. 1083 december 6th 1971, which is still in effect , that recognized all installations and materials realized under the UNI-CIG[105] norms as complaint to the rules of good procedure for safety.

The civil code treats the matter as well, in book IV about obligations, specifically in title I: "Obligations in general", article 1176 on qualified diligence states: "in the field of installations, professionalism is a legal obligation[106]", and in title IX: "Unlawful acts", article 2050 on "liability for the exercise of dangerous activities[107]" introducing the responsibilities for those performing dangerous activities, who have to prove that everything has been done on their part for the correct fulfillment of the service.

The criminal code also deals with the matter with title III about offenses, in chapter I: "completed and attempted offenses" specifically with article 40[108] "causality relationship", that states that "failing to prevent an event that one has a legal obligation to prevent is equivalent to causing it".

Hence the negligence on safety assurances in the distribution of natural gas is condemned by Italian law, forcing distribution companies to comply, as first obligation, to all safety procedures during the distribution activities.

Hereby, it is important that the model incorporates the current obligations via the addition of an element of safety constraint, by keeping the number and the priority of the leaks that are currently

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[104]Specific rules of good practice, article 1: "All materials, devices, installations, and systems powered by combustible gas for domestic use and similar purposes must be made according to the specific rules of good practice, for the protection of safety."

[105]According to law 1083/71, UNI-CIG standards are the specific rules of good practice, article 3: "The materials, devices, installations, and systems powered by combustible gas for domestic use, as well as the gas odorization mentioned in the previous articles, manufactured according to the specific safety standards published by the National Unification Body (UNI) in tables under the designation UNI-CIG, are considered to comply with the rules of good practice for safety."

[106]Civil code: book IV - Obligations; Title I: obligations in general; article 1176: qualified diligence: "In the performance of obligations related to the practice of a professional activity, diligence must be assessed with regard to the nature of the activity carried out."

[107] Civil code: book IV - Obligations; title IX: unlawful acts; article 2050: liability for the exercise of dangerous activities: "Anyone who causes harm to others in the performance of a dangerous activity, by its nature or by the nature of the means used, is liable for compensation unless they prove they have taken all appropriate measures to prevent the damage."

[108] Criminal code: title III - The offense; chapter I: completed and attempted offenses; article 40: causality relationship:"No one can be punished for an act considered a crime by law if the harmful or dangerous event, upon which the existence of the crime depends, is not a consequence of their action or omission. Failing to prevent an event that one has a legal obligation to prevent is equivalent to causing it. An act is intentional when the individual acts with knowledge and will (envisioning and realizing the intended event). An act is negligent, or against intention, when the event, even if foreseen, is not intended by the individual and occurs due to negligence, imprudence, or incompetence, or due to failure to comply with laws, regulations, orders or rules".

classified as immediate priorities as constant for the priorities reclassifications and the following analysis.
Currently, the regulator establishes four priority classes related to the threat every leak has when located, from the most dangerous to the least dangerous.
The classes are:
- A1: immediate priority, must be eliminated in 24 hours.
- A2: high priority, must be eliminated in 7 days.
- B: medium priority, must be eliminated in 30 days.
- C: low priority, must be eliminated in 180 days.

The source does not influence the prioritization of leaks but exhibits the location of the leak relative to the ground, dividing the leaks in aboveground leaks, underground leaks, and gas meter leaks, all of three presenting different characteristics that influence their importance.
Back to table 7 to review the current status for what regards the current time budget overview as it has been done for the budget constraint model.

	Priority	Source	Leaks number	Repair time (h)	Personnel workload (h)	Priority budget (h)	Share percentage
Current time budget overview	Immediate priority (A1)	Aboveground	6.484	0,5	3.047,48	15.351,42	31,78%
		Pipelines	955	4,6	5.990,50		
		Components	1.302	4,6	4.393,96		
		Gas meter	5.078	0,4	1.919,48		
	High priority (A2)	Aboveground	59	0,5	27,73	3.795,95	7,86%
		Pipelines	592	4,6	1.044,43		
		Components	227	4,6	2.723,79		
	Medium priority (B)	Aboveground	40	0,5	18,80	8.084,35	16,74%
		Pipelines	1.313	4,6	2.024,44		
		Components	440	4,6	6.041,11		
	Low priority (C)	Aboveground	16.478	0,5	7.744,66	21.067,36	43,62%
		Pipelines	1.478	4,6	2.238,89		
		Components	931	4,6	4.283,53		
		Gas meter	5.923	0,4	6.800,28		
Total	All	All	41.300		48.299,09	48.299,09	100%

Notes: The table shows how the current time budget is formed, dividing every priority class in sources and exhibiting the number of leaks related to every source for every priority, with the relative repair time and the personnel workload dedicated, which is calculated with equation (1), the last two columns show the priority budget expressed in hours and the share of such budget over the total of workload hours.

Table 58 *Current time budget overview*

The table provides an overview of the time budget allocation in terms of hours of work required to repair methane leaks, broken down by priority and leak source.

The last three columns are particularly important for understanding the operational impact and the distribution of company resources since they express the personnel workload for every source in every priority class and the total workload associated with every priority class.
The budgeting work done in the previous paragraph grats the possibility to jump directly to the budget constraint outlining, that was expressed with table 41, from that, to that, the safety constraint will be added.
Since the use of the monetary budget stays the same for the two models the methodologies used to calculate it stay the same, hence the procedures are equal and the hourly personnel cost of leak repair is set at 334,19 € (tab.43 for reference), equal for every leak since the cost of personnel does not change with respect to the different leak source.

Personnel cost	€ 16.140.934,80
Total workload (h)	48.299,09
Hourly cost	€ 334,19

Notes: The table shows the personnel costs that the company has for leak repair procedures, the total workload that the Company operators spend by working on the leak repair and the hourly cost of leak repair procedures

Table 59 *Leak repair costs*

The monetary budget, set as in the previous model will help with the following procedures where the leaks, that have their priority changed after been reprioritized with *P*, will be reorganized using the budget as constraint for class formation.

A1	A2	B	C	Personnel cost
€ 5.130.247,92	€ 1.268.557,45	€ 2.701.687,04	€ 7.040.442,39	€ 16.140.934,80

Notes: The table shows the monetary budget the company allocates for every leak priority class in Euros, dividing the budgeting in priority classes and with the last column exhibiting the total costs that are kept equal to the total personnel costs

Table 60 *Monetary budgeting*

The classes will be filled, from the highest priority to the lowest, with the leaks being placed into a certain class until the budget allocated for that class is filled, then moving to the following class until all leaks have been classified.
The A1 budget and priorities will stay the same, due to the addes safety constraint, hence the filling of classes will start from class A2 up to class C, ensuring that the Company prioritizes those leaks that represent a immediate threat to end consumers and citizens safety.

4.1.3.1 New priority classes

The leak reclassification that will be performed adding the safety constraint is very similar to the one performed in chapter 4.1.2.1, as all procedures are the same but immediate priority leaks are not considered in the new classification.
The leak prioritization process is finalized then by using the rankings exhibited in table 6, adjusted by removing the A1 classified leaks, with which it is possible to establish new leak repair priority classes by crossing the leak priority with the budget constraint estimated earlier in the document.

Source	Operating pressure	Pre-localization	Leak number
Underground	MP	TPN	482
	LP	TPN	305
	MP	CSI	38
			1.757
			801
	LP	CSI	1.598
Aboveground	LP	TPN	14.459
		CSI	2.118
Gas meters	LP	TPN	5.381
		CSI	542

Notes: Priority rankings developed by the implementation of equation P divided by source, operating pressure, pre-localization method and the respective number of leaks interested, version of table 6 adjusted not considering leaks that are classified as immediate priority.

Table 61 *Leak elimination priority ranking*

Table 22 harks back to table 8 and 10 showing the time budget chosen for budget allocation and the relative monetary budget allocation, without the budgets related to A1 priority classes
The budget will help to settle the class of priority following the new priority rankings, and the class budget values will be used as threshold that will be progressively filled handling the leaks with the highest priority given by the value of *P*, showed in table 21.

	High priority	Medium priority	Low priority
Time budget (h)	3.795,95	8.084,35	21.067,36
Monetary budget	€1.268.557,45	€2.701.687,04	€7.040.442,39

Notes: The table shows the monetary budget the company allocates for every leak priority class in Euros, and the relative time budget from which the monetary budget has been calculated from, dividing the budgeting in priority classes and with the last column exhibiting the total costs that are kept equal to the total personnel costs.Version of table 11 adjusted not considering leaks that are classified as immediate priority

Table 62 Monetary and time budgeting

The following steps are the same that have been performed to develop the first model, hence dividing the sources by their overall costs of repair as estimated
Withe the cost per leak values that have already been estimated in the previous budget constraint model and are not changing for the model we are addressing in this chapter.
To ensure the robustness of the calculation all the procedures have been done again, excluding the immediate priority leaks.

$$Overall\ source\ repairing\ cost\ =\ hourly\ leak\ repair\ cost\ *\ overall\ source\ repairing\ hours$$

Source	Hourly cost (€)	Overall repair time (h)	Overall repair cost (€)
Aboveground	€ 334,19	7.791,19	€2.603.715,73
Gas meters		2.238,89	€748.209,65
Underground		22.917,58	€7.658.761,51
Total		32.947,67	€11.010.686,88

Notes: The table shows for the different leak sources the common hourly personnel cost, the specific overall repair time dedicated to repair leaks belonging to the specific source and the result of their multiplication expressing the overall repair cost for each leaking source. Version of table 12 adjusted not considering leaks that are classified as immediate priority

Table 63 Overall repair costs

Then by using the number of leaks that belong to that source it has been calculated the cost per leak for every specific source, which will be then used to reorganize the different priority classes by filling the current priority class monetary budgets.

$$Cost\ per\ leak\ =\ overall\ source\ repairing\ cost/\ source\ leak\ number$$

The result of the division is exhibited in table 13.

Source	Overall repair cost (€)	Leak number	Cost per leak (€)
Aboveground	€ 3.622.144,44	23.061	€ 157,07
Gas meters	€ 1.389.676,57	11.001	€ 126,32
Underground	€ 11.129.113,79	7.238	€ 1.537,60
Total	€ 16.140.934,80	41.300	

Notes: The table shows for the different leak sources, the specific overall repair cost allocated by the Company, expressed in euros, the number of leaks belonging to the specific source and the result of their division expressing the specific cost per leak repaired for each leaking source, expressed in euros. Version of table 13 adjusted not considering leaks that are classified as immediate priority

Table 64 Cost per leak

With the cost per leak value it is possible then to proceed with the reorganization of the priority classes from high priority to low priority, current A2 to C, with the premises that have already been highlighted for the previous model reorganization.
Since the class budget has been outlined by using the time value, in order to account for different sources leak repair, the filling by number of leaks won't be completely precise, leaving space between the number of leaks reorganized and the budget set for every class.
In order to overcome such hurdle the budgets have been respected by maximizing the number of leaks without surpass the budget thresholds in immediate, high and medium priority class, by then surpassing the budget only when it came to low priority class. By doing so the overall budget has been respected as well as afore-mentioned classes, by pushing down leak repair, eventually resulting in a higher cost for low priority repairs that is higher than the relative threshold.

Source	Operating pressure	Pre localization	Leak number	Leak repair cost (€)	Total repair cost (€)	Cumulative costs (€)	New priority	Class budget (€)
Underground	MP	TPN	482	€ 1.538	€ 741.121	€ 741.121	High priority	€ 1.268.557
	LP	TPN	305		€ 468.967	€ 1.210.087		
	MP	CSI	38		€ 58.429	**€ 1.268.516**		
			1.757		€ 2.701.555	**€ 2.701.555**	Medium priority	€ 2.701.687
			801		€ 1.231.614	€ 1.231.614	Low priority	€ 7.040.442
	LP	CSI	1.598		€ 2.457.077	€ 3.688.691		
Aboveground	LP	TPN	14.459	€ 157	€ 2.271.046	€ 5.959.737		
		CSI	2.118		€ 332.670	€ 6.292.407		
Gas meters	LP	TPN	5.381	€ 126	€ 679.743	€ 6.972.149		
		CSI	542		€ 68.467	**€ 7.040.616**		
Total			27.481		€ 11.010.687	€ 11.010.687		€ 11.010.687

Notes: The table shows how the reclassification is performed, dividing the number of the leaks following the rankings established in tab 21.
The table exhibits the number of leaks that for every operating pressure and pre-localization method fill the new priority classes by showing their number, the relative source leak repair cost, expressed in euros, the total repair cost , expressed in euros, the cumulative costs , expressed in euros, highlighting the values that fill the class budgets, the new priorities of such classes and the budget constraint.
The last row serves to check that all totals are the same, leak number total, the total repair costs for all leaks, the cumulative cost resulting by the sum of the highlighted cumulative costs and the class budget.

Table 65 Budget and safety constraint model priority classes reclassification

The priority classes that result from the reclassification are the following:

<table>
<tr><th>Budget and safety constraint model priorities</th><th>Total number</th><th>Number</th><th>Source</th><th>Pressure</th><th>Pre localization method</th></tr>
<tr><td rowspan="3">Immediate priority</td><td rowspan="3">3.336</td><td>1.333</td><td rowspan="7">Underground</td><td>MP</td><td>TPN</td></tr>
<tr><td>818</td><td>LP</td><td>TPN</td></tr>
<tr><td>1.185</td><td rowspan="3">MP</td><td rowspan="3">CSI</td></tr>
<tr><td>High priority</td><td>825</td><td>825</td></tr>
<tr><td rowspan="2">Medium priority</td><td rowspan="2">1.757</td><td>1.143</td></tr>
<tr><td>614</td><td rowspan="2">LP</td><td rowspan="2">CSI</td></tr>
<tr><td rowspan="5">Low priority</td><td rowspan="5">35.382</td><td>1.320</td></tr>
<tr><td>19.766</td><td rowspan="2">Aboveground</td><td rowspan="2">LP</td><td>TPN</td></tr>
<tr><td>3.295</td><td>CSI</td></tr>
<tr><td>9.976</td><td rowspan="2">Gas meter</td><td rowspan="2">LP</td><td>TPN</td></tr>
<tr><td>1.025</td><td>CSI</td></tr>
</table>

Notes: The table shows how the reclassification results in the new priority classes, diving them by the total number of leak that belong to that priority class, and how that total number is composed specifying the leaks that compose it divided in source, pressure and pre localization method. Version of table 15 adjusted not considering leaks that are classified as immediate priority

Table 66 *Budget and safety constraint model priority classes*

4.1.3.2 Emission estimation

As it has been done in the previous chapter the estimation of natural gas emissions is performed on the elimination time, since the new priority classes changes will have effects on that phase of the leak existence, since the priority of a leak impacts the scheduling time, hence the moments following the localization of the leaks.

$$E = N * t_2 * EF \qquad (2)$$

Where:

- E are the estimated emissions
- N is the number of leaks
- t_2 is the elimination time expressed in hours
- EF is the emission factor expressed in standard cubic meters per hour

In order to accomplish the estimation the leaks have been summed up by operating pressure and pre-localization method, to follow the groups established earlier in the document.

$$Total\ t_2 = N * t_2$$

The results are exhibited in the table below:

Budget and safety constraint model priorities	**Source**	**Operating pressure**	**Pre localization**	**Number**	**Elimination time (h)**	**Total elimination time (h)**
High priority	Underground	MP	TPN	482	69,31	33.405,01
		LP	TPN	305		21.138,03
		MP	CSI	38		2.633,59
Medium priority				1.757	363,40	638.493,80
Low priority				801	973,45	779.733,45
		LP	CSI	1.598		973,45
	Aboveground	LP	TPN	14.459	150,10	2.170.295,90
			CSI	2.118		317.911,80
	Gas meters	LP	TPN	5.381	8,10	43.586,10
			CSI	542		4.390,20
Total				27.481		4.012.561,33

Notes: The table shows how the total elimination time is estimated, diving the results by new priority, emission source, operating pressure and pre-localization method. The new total elimination time, expressed in hours is the result of the multiplication between the current elimination time, expressed in hours and the number of leaks belonging to the new priority classes divided by the factore aforementioned.

Table 67 *Budget and safety constraint model total elimination time*

Once the values for t_2 have been estimated it is possible to follow the time estimation with the emissions estimation by multiplying the total elimination time, that now will be the emission activity factor, for the different source emission factors, showing a different version of equation (2)

$$E = AF * EF \quad (2)$$

The results are showed in the following table:

Budget and safety constraint model priorities	**Source**	**Operating pressure**	**Pre localization**	**Number**	**Total elimination time (h)**	**Emission factors (scm/h)**	**Estimated emissions (scm)**
High priority	Under ground	MP	TPN	482	33.405,01	0,24	8.017,20
		LP	TPN	305	21.138,03		5.073,13
		MP	CSI	38	2.633,59		632,06
Medium priority				1.757	638.493,80		153.238,51
Low priority				801	779.733,45		187.136,03
		LP	CSI	1.598	1.555.573,10		373.337,54
	Above ground	LP	TPN	14.459	2.170.295,90	0,01	21.702,96
			CSI	2.118	317.911,80		3.179,12
	Gas meters	LP	TPN	5.381	43.586,10	0,01	217,93
			CSI	542	4.390,20		21,95
Total				27.481	5.567.160,98		752.556,43

Notes: The table shows how the emissions related to the priority classes changes are estimated, diving the results by new priority, emission source, operating pressure and pre-localization method. The new estimated emissions, expressed in standard cubic meters of natural gas is the result of the multiplication between the total elimination time, expressed in hours and the emission factors of every source, expressed in standard cubic meter per hours grouped by the factors aforementioned.

Table 68 *Budget and safety constraint model estimated emissions*

The results show a total volume of natural gas emitted of 379.452,52 standard cubic meters (scm) but it does not take into account the amount of natural gas gas that is emitted out of immediate priority leaks, which is equal to 3.022,62 standard cubic meters of natural gas, bringing the total up to 755.579,05 standard cubic meters (scm) of natural gas.
Natural gas that when converted in methane, knowing that the average composition of natural gas in the italian pipeline system is made by 92% of methane, show a result of 695.132,73 m^3 methane emitted, which is equal to 20.714.955 m^3 of carbon dioxide equivalent when multiplied by the IPCC global warming potential (GWP) for methane of 29.8.

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Natural gas (scm)	755.579,05
Methane (m^3)	695.132,73
Carbon dioxide (m^3)	20.714.955

Notes: New estimated emissions expressed by different measure, first row: natural gas estimated emissions expressed in standard cubic meters of natural gas; second row methane estimated emissions expressed in cubic meters of methane (CH_4); third row: carbon dioxide equivalent estimated emissions expressed in cubic meters of carbon dioxide equivalent (CO_2eq)

Table 69 *Budget and constraint model estimated emissions*

To have a better comprehension of the changes generated by the reorganization of priority classes it is useful to compare the results of the two schemes relative to emissions.
In order to compare the results the overall emissions calculated with the same methodology have been estimated, where it can be seen that the current emissions that arise from the elimination time of leaks existence are the following:

Natural gas (scm)	757.466,67
Methane (m^3)	696.869,34
Carbon dioxide (m^3)	20.766.706

Notes: Current estimated emissions expressed by different measure, first row: natural gas by estimated emissions expressed in standard cubic meters of natural gas; second row methane estimated emissions expressed in cubic meters of methane (CH_4); third row: carbon dioxide equivalent estimated emissions expressed in cubic meters of carbon dioxide equivalent (CO_2eq)

Table 70 *Current estimated emissions*

Now by comparing them it is possible to value in terms of emission differences the changes that are registered by the new priority classification

	Budget and constraint model estimated emissions	Current estimated emissions	Emissions difference
Natural gas (scm)	755.579,05	757.466,67	-1.887
Methane (m^3)	695.132,73	696.869,34	-1.736
Carbon dioxide (m^3)	20.714.955	20.766.706	-51.750

Notes: Difference of estimated emissions expressed by different measure, first row: natural gas by estimated emissions expressed in standard cubic meters of natural gas; second row methane estimated emissions expressed in cubic meters of methane (CH_4); third row: carbon dioxide equivalent estimated emissions expressed in cubic meters of carbon dioxide equivalent (CO_2eq)

Table 71 Estimated emissions difference

Table 68 shows in it's last column the difference in emission estimation between the current emissions, in the second column, and the new emissions, showed in the first column.
The results are positive highlighting a decrease in emissions when the priority changes to from a safety-driven prioritization classification to an environmental-driven classification.
The abatement prioritization would decrease the total amount of emissions by more than 30% which can be considered a valid result, especially if it is related also to the decrease in emissions per unit of time worked, which expresses an increase in efficiency in the use of working hours.

Difference (scm)	-1.887
Difference %	-0,25%
Emissions per unite time worked	-0,04

Notes: The table shows the difference in natural gas emission estimation, expressed in standard cubic meters of natural gas, the percentage difference resulting from the changes in prioritization and the difference in emissions per unite time worked, result of the difference between the ration between the total workload and estimated emissions, current and new.

Table 72 Estimation emissions difference metrics

The addition of the safety constraint killed the emission abatement showing little to no difference from the current leak elimination practices to the practices and the prioritization that is proposed by the model.
That also express the big differences between the different priority classes, since from the medium to the low priority classes the difference is equal to 150 days.
With a simple estimation, if it would happen that the underground leaks that in the model were treated as if they belonged to the medium priority the emissions estimated for the model would decrease of 47% which is an astonishing result, but in order to accomplish such result investment have to be made in leak repair operations by the Company either by its spontaneous initiative, or do to a stricter time limit imposed by the regulator.
To be fair, operational time limits are completely respected by the company that on average eliminates such leaks in little more than 30 days, which is still 150ish days less than what the regulator allows.

4.1.3.3 Benefit analysis

The benefit analysis sounds almost useless once the results of estimation differences have been outlined, but for completeness it has been added to the document.
With that said it is possible to estimate that every cubic meter emitted directly to the atmosphere if priced by using the EU ETS CO_2eq price has a value of 1,83€ as well as the market price for every standard cubic metre of methane that is released onto the atmosphere without being used for energy purposes, set at the PSV wholesale price of 0,50€
With the unit values it is possible to perform the benefit analysis, since the costs have been kept equal to zero by the budget constraint.

	Unit cost	Emission difference (m^3)	Benefit
Economic benefit	€ 0,45	1.887	€ 849
Environmental benefit	€ 1,83	1.736	€ 3.176

Notes: The table shows the different benefits that arise from the change in prioritization, the first row shows the economic benefits:
first column: the cost per unit expressed in euros per standard cubic meter of natural gas emitted; second column: natural gas emissions abated by the change in prioritization expressed in standard cubic meters of natural gas; the third column economic benefit related to the abated natural gas emissions resulting by the multiplication of the unit cost for the emissions abated. The second row shows the environmental benefits: first column: the unit cost expressed in euros per cubic meter of methane emitted; second column: methane emission abated by the change in prioritization expressed in cubic meters of methane; third column: environmental benefit related to the abated methane emissions resulting from the multiplication of the unit time and the abated methane emissions expressed in euros.

***Table 73** Budget and safety constraint model benefits*

The values expressed in table 73 are the monetary benefits arising from the change that the budget and constraint model in priority evaluation.
The economic benefit reflect the abated cost that the decrease in natural gas emissions bring to the market, which is equal to the market cost of the recovered natural gas, while the environmental benefit is intended as the externality connected with the greenhouse gas potential of methane and reflects the abatement of methane in the atmosphere.
The sum of the two reflect the total social benefits that the changes would bring to society.

Economic benefit	**Environmental benefit**	**Social benefit**
€ 849	€ 3.1764	€ 4.5025

Notes: The table shows the different benefits arising from the changes in prioritization of leak repair, expressed in euros.

***Table 74** Budget and safety constraint model benefits*

The results are close to zero and follow the trend that have been seen in the emission estimation chapter related to the budget and safety constraint.
As expressed above, the harmony of physical safety and environmental abatement are not easy to be configured without the addition of further investments in leak elimination operation, such to decrease the elimination time, mainly of low prioritized underground leaks.

4.1.3 Considerations

The results of the model above give interesting insights by focussing on the emissions arising from the elimination time, which is equal to the post-localization time.
It is possible to prioritize emissions by their environmental impact by organizing them into a ranking that poses the focus on how their repair affects environmental results.
The estimations performed imply that without improvements in leak elimination, with the solely aim to decrease such elimination time, the Company is forced to choose either physical safety or environmental safety, with the former being encouraged, and even forced, by the Italian law.
While it is possible to score positive results, expressed in a social benefit of 590.752 €, equal to 195.366,65 cubic meters of methane abated, by fully committing to an environmentally-based framework, such approach lacks in safety considerations, making it impossible to apply operatively.
On the other hand ensuring safety limits the environmental prioritization resulting in very little improvements for what regards fugitive emission abatement, resulting in 4.5025 € of social benefits.
The regulator on their end does not push towards a decrease by keeping the elimination time related to the priority classes as high as 180 days, which is an elimination time almost 150 days higher than what the Company performs currently in underground leak elimination.
The distance between the regulator and the Company performances shows lack of awareness by the side of the policy maker that results to the unwillingness to target climate goals in the natural gas distribution industry.
The potential decrease in maximum elimination time allowed by the regulator will force companies ,that are currently exploiting the time granted by class C of the prioritization framework, to increase investments in order to decrease such elimination time, leading to a smaller amount of emissions derived by the lower scheduling time.
Currently in fact companies could use priority classes to postpone leak elimination, with the exceptions related to the leaks categorized of immediate priority.
The high number of the poles, in leak prioritization, expresses the fact that once a leak is recognized not to be physically armful, there is a very high chance that is placed as C class, hence increasing it's emissions.
The amount of emissions estimated for same leak, if classified as medium priority class instead that as high priority class are 4 times higher, for aboveground leaks, and 5 times higher when considering underground leaks[109]; the ratio becomes smaller when the difference is from medium priority classified leaks and low priority classified leaks where the aboveground leaks show an increase of double the medium class estimated emissions and the underground leaks more than double.
Parlare di valori assoluti.
It is still important to remember that post-localization emissions are only a little fraction of the integrity of emissions arising from the distribution of natural gas, accounting only for 4% of the total.
Investing onto leak elimination will then be an expensive investment, since the personnel expenses[110] for leak repair are 8 times more consistent than the counterpart allocated to leak detection[111], with a low ceiling of return in terms of emission abated, but it will be certain and result in safe, although small, returns.
The next paragraph will serve as an in-depth examination of leak detection campaigns and how mitigation strategies can affect the pre-localization existence of a leak, by focussing on company scheduled inspections and citizen engagement.

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[109] Results are given by confronting the average elimination time between A2 and B classified leaks
[110] Annex III.I.II - Table XLIX
[111] Annex III.I.II - Table XLX

4.2 Mitigation strategies in fugitive emissions detection

What if instead of focussing on the post-localization time of a leak companies and regulations prioritizes investments and actions onto the pre-localization existence, hence onto latency phase and localization phase, of it.

The possible actions that can be performed to decrease the latency phase follow multiple paths, and the main ways are through increasing network inspection and enhancing third party notified leaks as both have showed to accomplish results in time abatement.

From the company side then, in a situation of resource allocation, is it more efficient to invest in decreasing the elimination time or to assign budget to increase leak detection procedure?

Does the regulator, on the other hand, pursue policies that are able to efficiently engage citizens and end-consumers in leak detection?

Developing answers to such question is the main objective of the following chapter, and in order to accomplish that the issues have been tackled separately since, although the target is the same, the approaches differs to one another and so the methodologies.

In 4.2.1 Company data related to network inspections have been analyzed, understanding the status quo and current procedures and the current costs related to such procedures with respect to the environmental benefits generated, developing a brief cost-benefit analysis of network inspection procedures. Successively the cost benefit analysis has been compared against what the same investments would have meant if the allocation was onto faster leak elimination, proving the more efficient emissions abatement investment allocation.

Later on, in 4.2.2 the current regulator policies that norm third party notified leaks have been examined with a hand lens pointed to the economic transfer that the regulator issued related to the Company performances on third party notified leaks.

The transfer is analyzed in all it’s factors understanding the reasonings behind examining if the measure is coherent with the climate change reduction targets that are issued by the European Union.

The considerations that characterize paragraph 4.3 then hark back to the this introduction answering to the questions afore-posed, examining all insights that arise from the analysis, pointing possible solutions and issues that have to be pursued or corrected, visioning all leak detection and repair procedures and policies from an environmental standpoint.

4.2.1 Increasing inspections

An increase in inspections would require the company to inspect more kilometers of pipelines and network throughout the year, reducing thereby the time between inspections of the same pipeline or component.

The current inspection performances reached by the Company show an average inspection rate of 8.057,37 kilometers inspected every year, showing a rising trend over the years.

Year	Yearly inspected network (km)	Monthly inspected network (km)	Daily inspected network (Km)
2018	7.636,91	737,09	20,92
2019	7.590,56	695,66	20,79
2020	7.866,35	655,53	21,55
2021	8.347,89	632,55	22,87
2022	8.845,14	636,41	24,23
Average	8.057,37	671,45	22,07

Notes: The table shows the yearly inspected network over the analyzed years, as well as the monthly inspected network and the daily inspected network all expressed in kilometers..

Table 75 *Network inspected*

The increase in inspected network over the years is evident, with a downturn in 2019, showing a consistent trend, averaging an increase of 5% of the network inspected over the last three years that have been examined.

Year	Yearly inspected network (km)	Yearly difference (km)	Yearly difference (%)
2018	7.636,91	-	-
2019	7.590,56	-46,35	-0,61%
2020	7.866,35	275,79	3,63%
2021	8.347,89	481,54	6,12%
2022	8.845,14	497,25	5,96%
Average 2020-2022	8.353,13	418,19	5,24%

Notes: The table shows the yearly inspected network, paired with the yearly increase expressed in kilometers and in percentage increase.

Table 76 *Yearly increase in network inspections*

Considering that the network, throughout the years, expanded from 13.800 Km to 14.500 Km roughly, the inspection fully covers the whole of managed assets almost every 2 years; a special attention is dedicated to high pressure and dangerous materials pipelines, which are inspected every year, as outlined by regulations, and correspond to 5% of the whole network.

The results associated with the decrease in latency phase are shown in table 74, exhibiting how the changes in network inspection lead to consistent decreases in the estimated time related to the latency phase of a leak's existence.

Years	Network length (Km)	Network inspected (Km)	Latency time (h)
2018	13.971,13	7.636,91	16.025,74
2019	13.981,09	7.590,56	16.135,08
2020	14.562,16	7.866,35	16.216,47
2021	14.573,65	8.347,89	15.293,11
2022	14.568,20	8.845,14	14.427,98
Average	14.331,24	8.057,37	15.619,68

Notes: The table shows the yearly network length, the inspected network every year and the associated latency time expressed in hours..

***Table** 77 Latency time*

It is noticeable that a minimum change in network inspection leads to a decent percentage of change in the estimation of latency time of all leaks, which translates directly in emission abatement, also due to the fact that most of underground leaks, that have been shown to be those with the highest hourly emission factor, for the assumptions that have been used to estimate the latency time in this document, are those most affected by these changes.

Years	Latency time (h)	Yearly difference (h)	Yearly difference (%)
2018	16.025,74		
2019	16.135,08	109,34	0,68%
2020	16.216,47	81,39	0,50%
2021	15.293,11	-923,36	-5,69%
2022	14.427,98	-865,13	-5,66%
Average 2020-2022	15.312,52	-569,03	-3,62%

Notes: The table shows the yearly latency time, paired with the yearly increase expressed in hours and in percentage increase.

***Table** 78 Yearly increase in latency time*

The table shows how the company already abates emissions by simply increasing the network inspected on its own, without any regulamentatory push.

The soft increase related to the years 2019 and 2020 is associated with the increase in network length, which has not been offset by a higher increase in network inspections.

Another interesting insight arises when looking at the personnel expenses related to the leak detection procedures.
In fact, by looking at previous data, the first idea would be to imagine a rise in costs due to the increase in network inspected. Surprisingly, the costs sustained by the Company decrease overtime, expressing a fair increase in efficiency of operations.

Years	**Network length (Km)**	**Network inspected (Km)**	**Latency time (h)**	**Personnel costs (€)**
2018	13.971,13	7.636,91	16.025,74	€ 445.654,53
2019	13.981,09	7.590,56	16.135,08	€ 429.211,81
2020	14.562,16	7.866,35	16.216,47	€ 376.973,31
2021	14.573,65	8.347,89	15.293,11	€ 417.124,87
2022	14.568,20	8.845,14	14.427,98	€ 329.503,97
Average	14.331,24	8.057,37	15.619,68	€ 399.693,70

Notes: The table shows the yearly network length, the inspected network every year and the associated latency time expressed in hours..

Table 79 *Personnel cost*

The yearly difference is not perfectly consistent, showing how after an initial decrease in costs, 2021 exhibited an increase, which was then covered by a way-above-average decrease in 2022.

	Personnel costs	**Yearly difference**	**Yearly difference (%)**
2018	€ 445.654,53	-	-
2019	€ 429.211,81	-€ 16.442,72	-3,69%
2020	€ 376.973,31	-€ 52.238,50	-12,17%
2021	€ 417.124,87	€ 40.151,56	10,65%
2022	€ 329.503,97	-€ 87.620,90	-21,01%
Average	€ 399.693,70	-€ 29.037,64	-6,55%

Notes: The table shows the yearly personnel costs,paired with the yearly difference expressed in hours and in percentage difference

Table 80 *Yearly difference in personnel costs*

There are two main insights that can be drawn by table 40: the first is related to the possibility to decrease the latency time without the need for investments, resulting in abatement measures in a cost-zero environment; while the other is that it is not possible to estimate costs related to inspection targets with consistency.

Along with the personnel costs, the company showed a decrease in all related indicators; the hours worked every year inspecting the network, the hourly cost and the full time equivalent dedicated to network inspections. The most interesting value might lie in the variation of the coefficient for the hourly cost, which gives a percentage of 1,5% showing the least variations around the mean.

Years	Personnel costs	Hours worked	Hourly cost	Full time equivalent
2018	445.654,53 €	11.537,00	38,63 €	6,9
2019	429.211,81 €	11.337,00	37,86 €	6,8
2020	376.973,31 €	10.014,00	37,64 €	6,0
2021	417.124,87 €	11.195,00	37,26 €	6,7
2022	329.503,97 €	8.863,00	37,18 €	5,3
Average	399.693,70 €	10.589,20	37,71 €	6,36

Notes: The table shows the yearly personnel costs, the related working hours, the hourly costs and the full time equivalent for that hours worked.

Table 81 *Cost related indicators*

Another way to look at the data is to pair the hours spent inspecting the network to the results in kilometers inspected.

Years	Network inspected (Km)	Hours worked (h)	Hourly network inspected (km/h)
2018	7.636,91	11.537,00	0,66
2019	7.590,56	11.337,00	0,67
2020	7.866,35	10.014,00	0,79
2021	8.347,89	11.195,00	0,75
2022	8.845,14	8.863,00	1,00
Average	8.057,37	10.589,20	0,77

Notes: The table shows the yearly network inspected, the hours worked by the operatives in detection activities and the hourly network inspected for every year.

Table 82 *Hourly network inspected*

The results follow the same trend that has been shown in the last tables, with a recurrent increase in efficiency by the Company, that in 2022 reached the value of 1 kilometer of network inspected every hour.
Since the values show a positive trend, it is assumable that the values for 2022 will not worsen in future years; hence, these values can be used to roughly estimate the costs and the hours related to inspection targets, such as the possible yearly inspection of all the network, which, as for 2022 values, would be equal to 14.568,20 Km.
The chapter will continue by estimating the costs related to an increase in network inspection frequency rate, which would ensure a total coverage of the Company managed network and decrease the estimated latency time of leaks to a year, equal to 8760 hours.

The results that arise from the estimation are interesting: in order to grant a complete network inspection over a year, personnel costs should increase up to 535.314,98 €, thus a percentage increase of 62% for the personnel costs dedicated to leak detection.

Network inspected (Km)	Hours worked (h)	Hourly network inspected (km/h)	Hourly cost	Personnel costs
14.427,98	14.398,91	1,00	€ 37,18	€ 535.314,98

Notes: The table shows the network inspected, equal to the total Company's network, the hours worked to inspect that network at the rate of the hourly network inspected, expressed in kilometers for every hour, the hourly cost for inspecting and the personnel costs that arise. The estimation has been performed using 2022 data.

Table 83 *Estimated personnel costs to inspect all the network*

The cost will be high, but the estimated returns in terms of methane abated could offset the high price borne by the investments.
By inspecting the whole network every year, the resulting estimated latency time would decrease by 40% with respect to 2022 levels, and estimated emissions arising from the latency phase, which alone is responsible for 96% of total emissions, by 34% with respect to 2022 levels.
The positive results are a direct consequence of the increase in investments and would not be possible without the heavy increment of costs related to leak detection operations, which are all costs related to personnel expenditures.
From a benefit point of view the percentage reduction does not change, scoring a 40% decrease in environmental externalities, while from an absolute point of view the reduction, from a comparison between the estimated results and 2022 levels, results in a social cost drop of - 2.637.760,03 €, divided in -684.776,75 € related to economic costs and -€ 1.952.983,28 related to environmental costs, and as it has be highlighted before in the examination a decrease in costs equals to benefits, hence the above monetary values can be exhibited as benefits.

Economic benefit	Environmental benefit	Social benefit
€ 684.776,75	€ 1.952.983,28	€ 2.637.760,03

Notes: The table shows the different benefits arising from the investments related to a yearly leak detection of the network by the company.

Table 84 *Leak detection benefits*

The results show exceptional returns, as the economic benefits, calculated by pricing natural gas emissions for their wholesale price, show values that has not been seen before in the document, signaling the high efficiency in terms of estimated emissions abatement.
As it has been seen along the document environmental benefits, calculated by pricing methane emissions by the weighted price of carbon dioxide externalities in the EU ETS market, display a higher value related to the difference in unit price between economic and environmental impacts of fugitive emissions.
In order to reach such target, other costs has to be taken into account, as the fleet has to change accordingly to the increase, ad of 2022 the numbers of cars owned by the Company, equipped with leak detection sensor are 5, with every car inspecting 1.770,82 Km every year in detection procedures. In order to aim to the above-set target of yearly inspections the fleet would have to increase, either to 8, with the inspection efficiency slightly increasing, or to 9 to ensure a complete network inspection.

Each fleet component has an estimated price of 50.000 € comprising of the vehicle used and the sensor technologies mounted on such vehicle, for a upfront total cost ranging from 150.000 € and 200.000 €, costs that amortize over the years the fleet is used, which for sake of the document will be set at 10 years, resulting in about 20.000 € every year.
Fleet costs related to car gas do not account for a decisive increase in overall costs, as, with a usage of 14.427,98 Km, an estimated rate of 8 liters for every Km covered, and gas price at 1,80 €/l, the result shows an increase of about 30% from 2022 levels, but when compared to the personnel cost its impact results negligible, being equal to the 0,62% of the estimated personnel cost, in addition to such costs accounting for the maintenance of the sensors, equal to a yearly 2.700€ have to be deemed.
Once all costs and benefit related to an increase in leak detection measures designed to inspect the whole network in a year, it is time to compare them and understand if the results align with the aim of the intended measures.
The comparison has been performed in a double level, both comparing the investments to the social benefit and the economic benefit, as the target is to understand if the positive results offset the costs in both cost voices, since while social benefits is a metric composed by real prices and externalities not yet internalized their value is ambiguous, the value for economic benefit is related to the real value of the natural gas lost in the process hence connected to real costs that are beared by companies along the supply chain.

Metrics	**Social benefits**	**Economic benefits**
Difference	€2.076.448,05	€123.464,77
ROI	369,93%	22,00%

Notes: The table shows the cost benefit analysis arising from the investments related to a yearly leak detection of the network by the company.

Table 85 *Leak detection cost benefit analysis*

The analysis not only shows positive values from the social benefit comparisons, as it could have been expected by the higher price of environmental externalities, but also a positive results related to economic benefits.
The return on the investments exhibits a value for which, for every euro spent on network inspections the estimated return is 22% resulting in a positive investment, capable of giving positive returns to the economy.
Now, the trivial issue here is that the distribution company does not receive such benefits directly since it is not the owner of the gas distributed, hence not being able to cash out from their investments, which is always the case in terms of fugitive emissions abatement measures.
Leak elimination procedures, on the other hand, see the chance an of increase in efficiency granting emissions abatement with zero investments but, as it has been estimated above, in order to enhance a valuable abatement target investments are needed.
The main difference between the return of investments in reduction targeting the elimination phase of a leak is the ceiling they can reach, as the emissions arising from that existence phase of a leak correspond to 4% of the total emissions, hence, the returns have that limit, while investments in leak detection can provide a reduction up to 96% of emissions.
The elimination costs as mentioned in paragraph 4.1 depend on the specific source of the leak eliminated, underground leaks show higher unitary costs but have higher efficiency, resulting in lower costs per standard cubic meter of natural gas avoided.

Source	Emission factor (scm/h)	Leak elimination cost	Cost per scm avoided
Underground	0,24	€ 1.537,60	€ 6.406,65
Aboveground	0,01	€ 157,07	€ 15.706,80
Gas meter	0,005	€ 126,32	€ 25.264,55

Notes: The table shows the cost related to leak elimination, with respect to the source, the costs per standard cubic meter avoided is calculated in relation to the cost of the leak elimination and the emissions factor of that source.

Table 86 *Leak elimination costs*

Eliminating underground leaks after all evaluation has the major efficiency, granting a lower cost per standard cubic meter of natural gas avoided, while aboveground leaks and gas meter leaks show the inefficiency of operations, due to the low amount of natural gas that is emitted through such sources.
While for the leak detection it was not possible to examine the leak to leak investment, and the whole measure target was needed, for what regards leak elimination it is possible to analyze the cost and the benefits related to single leak elimination.
Table 44 shows the results in underground leak cost difference when compared to the benefits, priced by their wholesale costs in the Italian market and by the weighted cost of carbon dioxide externalities in the EU ETS market.

Metrics	Social	Economic
Difference	-€ 6.404,60	-€ 6.406,15
ROI	-99,97%	-99,99%

Notes: The table shows the cost benefit analysis arising from the investments related to a yearly leak detection of the network by the company, by using the costs related to underground leaks as example.

Table 87 *Leak detection cost benefit analysis*

While the difference value does not help with the analysis the ROI gives an interesting insight about the efficiency in investments in emission abatement measures.
The ROI related to leaked detection investments shows a positive value also without taking into account the environmental externalities, while when the focus moves to leak elimination all metrics show negative values, expliciting the inefficiency of the investments.
The reason is simple and very straightforward, as the elimination of leaks has no environmental target but it is needed for safety reasons and to ensure the quality of the service.
On another level the estimated costs related to a yearly inspection of 100% of the network could also serve as a target for the development of technologies capable of detecting leaks with the same results.
Setting the target and the relative cost for reaching that abatement target can enable the budgeting of technologic solution that become available over a certain cost threshold and are not currently used due to their higher fixed costs due to the upfront costs of investments with respect to the low fixed costs that the current operational procedures have.
The fact that in order to obtain such determining results the operational personnel costs, hence the variable costs, rise to such extent, opens up the possibility for Companies to invest up to the same amount to develop technologies able to perform better results, increasing the efficiency of leak detection, and offsetting the higher upfront investments and the possible higher fixed costs with lower variable costs for the target of lead detection performance established.

4.2.2 Citizen engagement

Third party notified leaks include on one part all the warnings alerted by citizens, as well as every detection notified by operative personnel, employed by the company or third parties, that are noticed during activities different from the scheduled network inspections.
In light of these detections, the company can initiate leak elimination procedures much more quickly than what is typical for leaks detected during inspections.
Citizen detection is, consequently, a key feature for companies' LDAR procedures, as it provides gratuitous aid in leak detection, allowing distribution companies to locate leaking components without needing for leaking detection personnel to intervene.
Citizen engagement and prosumeristic approach to leak detection has the possibility to steeply increase the efficiency in abatement operations, as emission estimations reveal.
Firstly, it is important to remember the differences in numbers between company scheduled inspection (CSI) and third party notified leaks (TPN).

Source	Pre-localization method	Leaks number	Percentage share
Aboveground	TN	19.766,00	47,86%
	CSI	3.295,00	7,98%
Underground	TN	2.151,00	5,21%
	CSI	5.087,00	12,32%
Gas meter	TN	9.976,00	24,15%
	CSI	1.025,00	2,48%
	TN	31.893,00	77,22%
	CSI	9.407,00	22,78%
Total	Total	41.300,00	100,00%

Notes: The table divides every source divided by Third-party notified (TPN) leaks and leaks found during company scheduled inspections (CSI) exhibiting the number of leaks belonging to that group and the share percentage over the total of leaks eliminated by the company over the years examined (2018-2022)

Table 38 *Pre-localization method numbers*

Table 38 exhibits the number of leaks that are detected following the two different pre-localization methods, and their share over the total of leaks detected during the five year timeline that has been examined in this document.
The numbers provide valuable insights into the issue: as clearly noticeable, third party notificed leaks hold a leading position with respect to those detected by the Company, with TPN being 77% of the total, while CSI is equal to 23%.
The difference then would lead to think that TPN leaks have the upper hand also in emission estimation, but the reality is quite the opposite.
Due to the high expected latency time that characterizes leaks found during scheduled inspections, the estimated results for emissions from such leaks are higher than those that would occur if the leaks were detected by third parties.

Comparing the estimated emissions divided by year and pre-localization methods, it is clear that the majority of emissions arise through company scheduled inspections, with an overall value over the five years examined that is roughly 5 times higher than the counterpart.

Years	Total estimated emissions m^3 methane		
	TPN	CSI	Total
2018	588.720,05	2.530.603,02	3.119.323,07
2019	586.749,68	3.691.504,86	4.278.254,54
2020	653.516,02	3.348.623,21	4.002.139,23
2021	619.233,09	3.037.551,89	3.656.784,98
2022	469.276,44	2.980.763,30	3.450.039,74
Total	2.917.495,28	15.589.046,27	18.506.541,56

Notes: The table shows the total estimated emissions arising from the Company's network, expressed in cubic meter of methane emitted, divided by the pre-localization method and the sum of the two

Table 26 *Total estimated emissions*

The insights provided by these two tables are evident: albeit the vast majority of third party notified leaks have a lesser environmental impact, they highlight the importance of citizen engagement for fugitive leak emissions abatement.

Maximizing the amount of leaks detected by citizens would bring about major accomplishments in emission abatement and, consequently, diminishing emissions.

While citizen help can decrease latency phase overall time and the emissions, it is not a substitute for company scheduled inspections, since not all leaks can be detected by their odorization component; hence, network inspections performed with sensors and qualified personnel still remain a major component of LDAR procedures.

The two methods must be employed simultaneously and concordantly, with third parties averaging in for the more voluminous and dangerous leaks, located in densely populated areas, while the Company inspections deal with the clean-up of hard-to-spot leaks due to their location or entity.

The cooperation between the two methods, although intuitive, still lacks incorporation by the Italian regulation, that still sees them as substitutes; moreover, Italian companies, as of now, are encouraged to increase their network inspections' frequency with the aim of decreasing third party notified leaks.

The Italian regulator developed an economic transfer as a way of rewarding companies that decrease third party notified leaks along the managed network.

From a safety and service standpoint the approach is reasonable , since a decrease of third party notified leaks presumes a decrease in fugitive emissions in densely populated areas, and/or a decrease in voluminous leaks that are detectable through smell.

Such a decrease would enhance both the safety as well as the quality of the service provided to citizens, who are currently the primary focus of the regulator; nevertheless, as previously mentioned in the document, the regulator still fails to incorporate in its frameworks the internalization of the environmental impact of fugitive emissions.

From an environmental perspective, the economic transfer can be deemed as outdated, contrary to options that would enable cost-free abatement of emissions. By aiming at taking out of the equation the possibility of roughly nullifying the latency phase of a leak, the regulator inadvertently increases fugitive emissions, in a way that is countercurrent to all efforts possibly employed by Companies to tackle the issue.

The economic transfer has already been presented in this document and a more detailed analysis will be performed now, examining how the transfer is calculated, the implications, already mentioned above, and the Company transfers.
The regulator, ARERA, explicitates the calculation of the economic transfer in “Delibera 569/19” which is the norm approving the regulations about distribution service quality and gas measurements for the period 2020-2025, and in article 42, entitled “Premi e penalità per la riduzione delle dispersioni segnalate da terzi”, it outlines the methodologies through which companies are granted monetary compensation or fees, depending on their performances regarding the reduction of third party notified detections.
After a first glance at equation (25):

$$Inc = (P_{disp} * 0,04) * Nu * 138 * \left(1 + \varepsilon_{pc} + \varepsilon_{p}\right)^{z} \tag{25}$$

The examination will analyze the different factors composing the economic transfer by following the commas of art.42:

- ***Comma 42.1***:

The indicator about the number of TPN leaks for every thousands end-consumer ($DT_{CONV.\ j,t}$) is calculated for every distribution network (j), often representing cluster of municipalities or cities, and for every year (t), following the formula:

$$DT_{CONV._{j,t}} = \left(\frac{10*DT_{j,t}+DTA_{j,t}}{N_{j,t}}\right) * 1000$$

where:

- DT is the number of TPN leaks detected in year *t* for distribution network *j* relative to the underground part of the network, and
- DTA is the number of TPN leaks detected in year *t* for distribution network *j* relative to the aboveground part of the network and to the gas meters.

The aim of this weighting is to level leaks that are easier to detect, such as those located above the level of the ground, with those located underground, making every underground TPN leak’s value 10 TPN aboveground leaks.

- ***Comma 42.2***:

Expresses the equality between the value $DT_{CONV.\ j,t}$ and the value $LivEff_{j,t}$ for network *j* in year *t*.

- ***Comma 42.3:***

The starting level for every network *j* is equal to the mean of its $LivEff_j$ for the time 2017-2019 weighted for the number on end-users:

$$Liv_{part_j} = \frac{\sum_{k=2017}^{2019} Liv_{eff_j} * NU_j}{\sum_{k=2017}^{2019} NU_j}$$

- ***Comma 42.4***

The regulators then defines two variables:

- An objective level (Liv_{Ob}) equal to 7,5 TPN leaks for thousands end-consumers
- A reference level (Liv_{rif}) equal to 3,5 TPN leaks for thousands end-consumers

Theselevels will be useful later for further calculations

- ***Comma 42.5***

For every distribution network j and every year t for the period 2020-2025, which is the period covered by the regulation, the tendency level is equal to:

$$T_{j.t} = max\left|T_{j.t-1} * (1 - \alpha); Liv_{ob}\right|$$

with α equal to:

$$\alpha_j = max\left|1 - \left(\frac{Liv_{ob}}{Liv_{part_j}}\right)^{\frac{1}{7}}; 2\%\right| \text{ with } \alpha_j \leq 7\%$$

where:

- $T_{j,t}$ is equal to the tendency level for distribution network j for year t
- T_j is set equal as $Liv_{part.j}$
- Liv_{Ob} equal to 7,5 as in *comma 42.4*
- α_j being the increase rate required by every distribution network j
- $Liv_{part.j}$ as the starting level for distribution network j as for *comma 42.3*

The equation serves the purpose to establish a progressive benchmark in order to incentivize the constant reduction of TPN detections, ensuring, by the choice of the maximum value, that the tendency level does not reach a level too low to be useful for the regulator purposes.
The value of $T_{j,t}$ depends on different factors as it has been highlighted, especially from the performance level over the years, with respect to the starting level set by Liv_{part}.
The reduction of TPN leaks directly affects the values of $T_{j,t}$, improving the performances with respects to previous years and to $Liv_{part,j}$ which is used as starting point for $T_{j,t}$ value.
By enhancing better performances the distance to the objective level (Liv_{Ob}).
The calculation for the years 2020-2025 keeps track of the previous year, incentivizing the continuos reduction of TPN leaks and an increase in all procedures that lead to such decrease.
For the year 2020 the equation would have looked like this:

$$T_{j.2020} = max\left|Liv_{part_j} * (1 - \alpha); Liv_{ob}\right|$$

while for year 2021:

$$T_{j.2021} = max\left|T_{j.2020} * (1 - \alpha); Liv_{ob}\right|$$

This change accounts for the improvements made the previous year (2020) adapting the value to the performance changes that have been accomplished by the company.
All segments are important to better understand how the main factor that influences the outcome of the transfer, basically the factor deciding either if the transfer is positive, a prize, or negative, a fee.

- ***Comma 42.7***

The value at hand is $P_{disp\ j,t}$ and as all indicators is calculated for every year ItI and every distribution network *j*:

$$P_{disp} = \frac{T_{j,t} - max\left(Liv_{eff_{jt}}; Liv_{rif}\right)}{Liv_{Ob}}$$

Where:

- $T_{j,t}$ is the tendency level of distribution network calculated as for *comma 42.5*
- $Liv_{Eff\ j,t}$ is the performance level for the distribution network *j* in year *t* as for *comma 42.2*
- Liv_{Ob} is the objective level as in *comma 42.4*
- Liv_{Rif} is the reference level as in *comma 42.4*

The result of P_{Disp} is rounded up to the third decimal and it is constrained in between -0,60 and 1,20, and if the value falls within the range [-0,05; 0,05] it is set to be considered as zero, signaling no deviation.

As we can see from the P_{disp} equation, the positive result depends on the performances scored by the company on TPN leaks detection, as a higher $T_{j,t}$ results in a positive value, directly linking the decrease in TPN to the positiveness of P_{disp}.

Now, let's bring back equation (25) relative to the economic transfer:

$$Inc = (P_{disp} * Q_{max}) * Nu_j * Val * \left(1 + \varepsilon_{PC_{j,t}} + \varepsilon_{P_{j,t}}\right)^z$$

where:

- Inc is the economic transfer from the regulator
- P_{disp} is the coefficient related to the delta of leaks reported by third-party as for *comma 42.7*
- Q is an arbitrary value set by the authority equal to 0,04
- Nu_j is the total number of final clients for the network *j*
- Val is an arbitrary value set by the authority with a value of 138€
- ε_{pc} as a coefficient representing a subsidy on cathodic-protected steel pipelines relative to distribution network *j* for year *t,* equal to the ratio between the protected meters and the total meters.
- ε_p as a coefficient representing a subsidy on smart monitoring for gas pressure regulation stations, relative to distribution network *j* for year *t* and it's equal to the ratio between the total number of the smart-monitored stations and the total number of stations.
- z is a weight equal to 1 in case P_{disp} is bigger or equal to 0, while it's equal to -1 if P_{disp} is a negative number.

Since P_{disp} is the only value that can be negative in the calculation of the economic transfer, it solely depends on the companies' performance in decreasing TPN leaks, hence companies are subsidized to decrease such value, leading back to the assumption that the regulator in a certain way fights against citizen engagement for emissions abatement.

By doing so, the regulator encourages companies to disincentivize citizens on leak notification, since an increase in TPN leaks would mean getting fined by the regulator, transforming a possible income in costs.

Article 42, moreover, expresses the possibility for distribution companies to lose the right to all possible positive economic transfers for a network with the presence of explosive incidents in such areas, proving that such explosions were not due to extenuating circumstances or caused by third parties.
Up to 2024 the years that have been evaluated for the economic transfers are until 2020, and for the years 2018, 2019 and 2020 the Company examined scores a positive economic transfer for the whole period:

Year	Economic trasfer
2018	€ 1.533.358,84
2019	€ 2.505.513,54
2020	€ 1.752.243,28

Notes: The table shows the economic transfer, expressed in Euros, which the Company examined in the document has been awarded for the years 2018-2020 by the regulator, due to the economic transfer method based on the performances scored in leaks notified by third parties (ARERA, 2024)

***Table** 7 Regulator economic transfer*

The Company examined throughout the document was able to score positive performances over the years exhibited in table 7, showing a constant decrease in third party notified leaks.
A insight that arises from the results and from the economic transfer equation is that a company could score negatively on different distribution networks, i.e different municipalities, but score a positive result on more densely populated areas, since the value takes into account the number of end-consumers connected to that distribution network (Nu), which then can offset all negative values giving an overall positive economic transfer to the company.

4.3 Considerations

Tackling fugitive methane emissions that arise from the latency phase of a leak existence has been proved to grant positive results in emissions abatement with both type of interventions: the former directed to increase leak inspection frequency rate, hence effectively decreasing the estimated latency time related to leaks detected during company scheduled inspections; the latter deals with citizen engagement, by creating ways to increase third-party detected leaks in order to nullify the latency phase, locating leaks before the company scheduled inspections reach that point of the network.
Company data showed great improvement in inspection efficiency over the years, exhibiting higher inspection frequency rates, involving less personnel, and decreasing costs, which resulted in decreasing latency time and an overall better performance in leak detection.
Efficiency in leak detection has the potential to highly affect fugitive emissions, and companies might want to focus on this aspect of a leak's existence in order to maximize their opportunities to decrease their impact on the environment.
An important aspect is related to the impact that investments would have in leak detections: by inspecting the whole network every year, the resulting estimated latency time would decrease by 40% with respect to 2022 levels, as well as estimated emissions arising from the latency phase, which alone is responsible for 96% of total emissions by 34% with respect to 2022 levels.
Investments show to result in a return of investment of 22% when accounting only the economic benefits, ROI that further increases when environmental benefits are taken into consideration as well, with a return of 368% the investments.
The results are self explanatory when compared with the same indicators relative to the investments in leak elimination which return of investments records a - 99%, due to the high inefficiency of leak elimination costs, which is explained by the safety design of such interventions.
With such results companies that want to decrease their environmental impact should highly focus investments on leak detections, by allocating the resources to an increase of network inspection rate, to reduce the latency time related to their network.
Increase in investments, related to emission abatement, could open up the possibility for backstop technologies to come into play, resulting in companies deciding to invest in increasing efficiency instead of increasing personnel expenses; the consequences are increased performances without the excessive costs that are related to high variable costs, which are expressed by labour intensive labour.
Citizen engagement works on a different level, but eventually goes in the same direction, not without some concerns and ambiguity.
While third party detection presents an optimal chance to nullify the latency phase of a leak, the way the regulator addresses this approach raises some concerns about its use as a climate tackling method.
Current regulation do not internalize environmental abatement in there frameworks, resulting outdated when in comes to reducing the impact of fugitive emissions.
The regulator, by enforcing safety and quality of the service, requires companies to decrease the number of third parties; to achieve and incentivize this, companies that ensure an overtime lower level of leaks detected by third parties are granted a prize, while those that do not reach the established decrease are fined by the regulator. This reward system encourages companies to increase their efforts in leak detection, since the idea that lies behind the concept of the economic transfer consists in stimulating companies to inspect their network more frequently every year, so as to cover the issues related to leaks in closed spaces or populated areas. Whereas the reasoning behind this concept is correct, there is also a possibility of it backfiring very rapidly, as it disincentivizes dialogue between companies and third parties regarding possible leaks and how to notify them, and it pushes companies to focus firstly on more populated areas, leaving the countryside as a second option in leak detection.

Furthermore, this type of regulatory measure, by decreasing the prosumeristic approach that is embedded in citizen engagement, neglects the possibility for further reduction in latency time, hence in emissions.
The regulator's failure in internalizing environmental based policies could lead to costs to the society amounting up to millions of cubic meters of methane; on the contrary, this would be avoided if a more collaborative approach between distribution companies and citizens were to be encouraged.
As of now, citizens are not urged to warn the company regarding a leak if it does not concern, directly or indirectly, their safety. This type of uncooperative measure, as well as similar actions that are disruptive to collaboration between companies and citizens, are in dire need of correction.
Citizens must be incorporated actively in leak detection programs, enabling them to create value for distribution companies; this would not only create positive environmental benefits, but would also allow companies, aware of not being fined because of end consumers calling, to better cover their network, intervene faster on leaks, deploying a better service as well as functional emission abatement.
Company communication directed towards the public must be clear and every gas meter should have contact information about how to report leaks, explicit instructions on how to behave accordingly and how to provide the company with the information needed to efficiently locate the leak once it is notified.
Awareness campaigns are required to educate every citizen on their local distributor, increase their understanding of gas leaks, how to prevent them and how to detect them, even when they happen to be outside.
Failing to do so means missing out on meaningful opportunities and, frankly, opportunities are all that is needed to make the difference.

Chapter 5 - The European regulatory landscape

5.1 EU targets and fit for 55

5.1.1 EU targets for 2050 and 2030

The European Union pledged its commitment to lead global climate action: in its “2050 long-term strategy” (2018), the Union mapped out the way forward, defining what is regarded as the long-term course of action to achieve the temperature objectives set by the Paris Agreement (2015).
The scenarios analyzed in 2019 via model-based quantitative analysis explore three tiers of possible paths to follow, which could lead to the potential range of greenhouse gas emissions (GHG) reduction needed for the EU to meaningfully contribute to the Paris Agreement’s temperature target of between 2°C and 1,5°C temperature change. This translates to a reduction of between 80% and 100% in the EU’s GHG emissions by 2050, with respect to 1990.There are various sectoral options among the ones explored as possible pathways to decrease the emissions of GHG: moderation of demand, technological options to decarbonize energy supply, in addition to the use of negative emissions.
The scenarios explored by the European Commission’s project represent a gradual but nevertheless significant change from the current path, incorporating a wide portfolio of mitigation chances.
The three main categories that are explored:

- The first category explores five scenarios. Albeit each of them is peculiar in their own way, their main focus points consist in incorporating efficient energy practices, deploying renewable energy and improving the transport system’s efficiency; similarly, their main scope is limiting global warming to below 2°C and reducing GHG emissions of circa 80% by 2050.
    - ELEC, switching from the direct use of fossil fuel to full electrification in all sectors, coming from net zero energy sources.
    - H2, hydrogen usage in industry, transport, and buildings.
    - P2X, E-fuels in industry, transport, and buildings.
    - EE, high development of energy efficiency in all sectors.
    - CIRC, massive development of circular economy, and increased resource and material efficiency.
- The second category has only one scenario: COMBO, seen more as a bridge scenario, which pairs the actions and technologies envisioned for the scenarios in the first category, but differs from it because a level of total deployment of each technology is not required; this strategy results in a net reduction of GHG close to 90% by 2050, compared to 1990 levels.

Both the first and second category scenarios underline the desire to continue efforts aimed at reducing emissions even after 2050, intending to decrease emissions towards net zero.

- The third category of scenarios is the most ambitious: it set on achieving net zero by 2050 and pursuing efforts to keep temperature changes under 1,5°C. This category intends on balancing out emissions that remain unabated by 2050 with negative emissions: in relation to land-use, worth including are LULUCF (Land Use, Land-Use Change, and Forestry) and sinks; unequivocally important is also spurring citizens towards cleaner lifestyle changes, choices that are beneficial for the climate, less carbon-intensive diets, sharing transport economy, limiting growth in air transport demand and a more rational use of energy demand and cooling.
    - 1.5°C TECH, based on a stricter COMBO scenario with increased development of bioenergy carbon capture and storage as well as carbon capture and storage technologies

- 1.5°C LIFE, based on a stricter COMBO scenario with increased development of circular economy, sustainable resource management, and lifestyle changes.

Long Term Strategy Options

	Electrification (ELEC)	Hydrogen (H2)	Power-to-X (P2X)	Energy Efficiency (EE)	Circular Economy (CIRC)	Combination (COMBO)	1.5°C Technical (1.5TECH)	1.5°C Sustainable Lifestyles (1.5LIFE)
Main Drivers	Electrification in all sectors	Hydrogen in industry, transport and buildings	E-fuels in industry, transport and buildings	Pursuing deep energy efficiency in all sectors	Increased resource and material efficiency	Cost-efficient combination of options from 2°C scenarios	Based on COMBO with more BECCS, CCS	Based on COMBO and CIRC with lifestyle changes
GHG target in 2050	-80% GHG (excluding sinks) ["well below 2°C" ambition]					-90% GHG (incl. sinks)	-100% GHG (incl. sinks) ["1.5°C" ambition]	
Major Common Assumptions	• Higher energy efficiency post 2030 • Deployment of sustainable, advanced biofuels • Moderate circular economy measures • Digitilisation				• Market coordination for infrastructure deployment • BECCS present only post-2050 in 2°C scenarios • Significant learning by doing for low carbon technologies • Significant improvements in the efficiency of the transport system.			
Power sector	Power is nearly decarbonised by 2050. Strong penetration of RES facilitated by system optimization (demand-side response, storage, interconnections, role of prosumers). Nuclear still plays a role in the power sector and CCS deployment faces limitations.							
Industry	Electrification of processes	Use of H2 in targeted applications	Use of e-gas in targeted applications	Reducing energy demand via Energy Efficiency	Higher recycling rates, material substitution, circular measures	Combination of most Cost-efficient options from "well below 2°C" scenarios with targeted application (excluding CIRC)	COMBO but stronger	CIRC+COMBO but stronger
Buildings	Increased deployment of heat pumps	Deployment of H2 for heating	Deployment of e-gas for heating	Increased renovation rates and depth	Sustainable buildings			CIRC+COMBO but stronger
Transport sector	Faster electrification for all transport modes	H2 deployment for HDVs and some for LDVs	E-fuels deployment for all modes	Increased modal shift	Mobility as a service			• CIRC+COMBO but stronger • Alternatives to air travel
Other Drivers		H2 in gas distribution grid	E-gas in gas distribution grid				Limited enhancement natural sink	• Dietary changes • Enhancement natural sink

Notes: Description of policy scenarios that look at interaction policies for the achievement of net-zero within 2050.

Table 1, *The update of the nationally determined contribution of the European Union and its Member States*, European Commission, 2020

Figure 15. *Long terms strategy options*

After an initial commitment, in 2020 the European Union adopted a new and more ambitious set of proposals set forth by the Commission to reduce net GHG emissions by 55%, 1990 levels, by 2030; this initiative replaced the previous strategy, which was to achieve a decrease of 40% by 2030, as it as deemed too feeble by the Commission. This high-reaching change in strategy by the Commission is geared towards putting the EU on the right track for achieving climate neutrality by 2050, which, to be reached, requires a major increase in environmental efforts.

The proposals are based on an impact assessment that is centered on the intricate braiding of economic, social and environmental aspects of the transition, so as to set a new and feasible target under a precise mix of policies.

Being the previous 2030 targets insufficient for a climate-neutral economy in 2050, as even by complying to them accurately only a 80% decrease in emissions would be achieved, the Commission's newly developed impact assessment focused on two main pillars:

- The overall increase in ambition for 2030 targets
- Feasibility of such increase and ways of achievement

The baseline used in the assessment was the existing 2030 climate framework, which consisted in planned climate and energy targets, alongside policy tools for their implementation. The policy options highlighted by the assessment to realize the defined targets are:

- Policy strategies regarding the scope of the target
    - Baseline scope: including domestic and international aviation emissions, but not maritime navigation emissions

    - Including intra-EU bunker fuel emissions: all emissions due to international aviation and international maritime voyages between two EU member states, but not between the EU and locations outside of the EU.
    - Including all EU bunker fuel emissions: all aviation and maritime voyages intra-EU, as well as 50% of all emissions due to incoming and outgoing aviation and maritime voyages extra-EU.
- The extent to which carbon pricing is expanded to sectors that are currently not covered by the EU Emissions Trading System
    - The current scope of ETS
    - Extension of ETS to sectors that are yet uncovered
- The level of intensity of energy efficiency policies
    - No intensification of energy efficiency policies
    - Low intensification of energy efficiency policies, increasing dedicated financing, additional guidance, and better implementation of the energy efficiency first principle.
    - Moderate intensification of energy efficiency policies, thus a moderate increase of the overall energy efficiency ambition and, to this end, an enhancement of the financial and other measures required
    - High intensification of energy efficiency policies, further intensifying policy measures at the EU level to ensure a greater increase of the overall energy efficiency ambition. For this purpose, additional elements to integrate the legislative framework and an enhancement of financial and other measures are required.
- The level of intensity of renewable energy policies
    - No intensification of policies regarding the deployment of renewable energy
    - Low intensification of policies, supported by non-regulatory policy instruments encompassing training, information campaigns, and financing.
    - Moderate intensification of policies, implementing off-shore strategies as well as increasing policies regarding energy communities.
    - High intensification of policies, including heating and cooling targets other than a further mainstreaming of low carbon and renewable energy as fuels.
- The role of policies related to the transport sector:
    - No intensification of transport policies
    - Low intensification of transport policies, driving improvements towards cleaner and more sustainable transport methods.
    - Moderate intensification of transport policies, thus moderate improvements towards more sustainable transportation methods as well as an increase in transport efficiency and lower thresholds for CO_2 standards in vehicles.
    - High intensification of transport policies, further intensification of sustainable and cleaner transportation methods, strong boost of carbon efficiency in the sector, and increased stringency of CO_2 standards for vehicles.
- The policies related to greenhouse gasses other than carbon dioxide
    - No additional contribution to non-CO_2 GHG reductions
    - Moderate increase in contribution to non-CO_2 GHG reductions, with policies that, from a bottom-up perspective rely on a win-win situation, alongside measures that address information imbalances and split incentives.
    - High contribution to non-CO_2 GHG reductions, requiring intermediate carbon prices similar to the ones regarding CO_2 policies.

- Very high contribution to non-CO_2 GHG reductions, requiring high carbon prices through the extension of carbon pricing tools.
- The role of land use, land-use change and forestry policies
  - Baseline LULUCF in State practices
  - Incentivising additional actions in the LULUCF sector

Together with these various policy options, the assessment also developed different scenarios via modeling, in order to explore all possibilities and the feasibility of each scenario. The approach allowed us to compare different scenarios, focusing on the different policies that would fit the different frameworks, as well as their coexistence and synergies.

The scenarios outlined by the assessment:

- BSL, baseline scenario, achieving 2030 targets
- REG, a regulatory-based scenario that achieves around 55% GHG reduction, through a strengthening and expanding of carbon pricing, combined with low intensification of transport policies; policies regarding energy efficiency and renewable energy are not increased.
- CPRICE, a carbon pricing-based scenario in which achievements settle around 55% GHG reductions, assuming carbon pricing to further extend and strengthen, combined with low intensification of transport policies; with no intensification of renewable energy or energy efficiency policies planned.
- MIX/MIX -50, a combined approach of the previous scenarios achieving around 55% GHG reductions, 50% in MIX -50, revolves around expanding both carbon pricing and moderately increasing the ambitions of policies with a higher limit to REG.
- ALLBNK, the most ambitious scenario, is the evolution of MIX that further intensifies fuel mandates for aviation and maritime transport and also increases the effort in decreasing no-CO_2 GHG emissions.

2030 Target Plan Policy Scenarios

	(REG) Policies and measures as main driver for GHG 55% target	(MIX)/ (MIX-50) Policies, measures and carbon pricing combined for GHG 55%/GHG 50% target	(CPRICE) Carbon pricing as main driver for GHG 55% target	(ALLBNK) Inclusion of all bunkers for GHG 55% target
Scope to asses GHG target ambition	All sectors including intra EU bunkers and LULUCF			All sectors including intra and extra EU bunkers and LULUCF
ETS Scope / Carbon Pricing	ETS scope: - Power, Industry, - Intra-EU aviation and navigation*	ETS scope: - Power, Industry, - Intra-EU aviation and navigation*, - Road transport, Buildings		ETS scope: - Power, Industry, - All aviation and navigation, - Road transport, buildings
EE policies	High intensification policies	Medium/low intensification policies	No additional measures compared to Baseline	Medium intensification policies
RES policies	High intensification policies	Medium/low intensification policies	No additional measures compared to Baseline	Medium intensification policies
Transport measures	High intensification policies (CO2 standards in road transport + RES, aviation and maritime fuel mandates + measures improving transport system efficiency)	Medium/low intensification policies (CO2 standards in road transport + RES, aviation and maritime fuel mandates + measures improving transport system efficiency)	Low intensification policies (CO2 standards in road transport + aviation and maritime fuel mandates + measures improving transport system efficiency)	Medium intensification policies (CO2 standards in road transport + measures improving transport system efficiency) High intensification of RES, aviation and maritime fuel mandates
non-CO2 policies	Medium intensification policies			High intensification policies
LULUCF policies	Baseline policies			

*Carbon pricing and carbon values are applied on extra EU aviation and navigation to represent ETS or other policy instruments regulating these sector's emissions (which can also stand for other policy instruments like CORSIA for aviation and technical and operational measures for both aviation and maritime).

Notes: Description of policy scenarios interactions for 2030.
Table 3, *Stepping up Europe's 2030 climate ambition*, European Commission, 2020

Figure 16. *2030 Target plan policy scenarios*

5.1.2 Fit for 55

The "fit for 55" package is composed of a comprehensive set of proposals designed to execute the above-mentioned targets, cementing the EU's drive as the green-transition leader. It consists of a bundle of interconnected schemes targeted at accomplishing a green transition by 2030 and beyond, developing furtherly ambitious legislation as well as covering normative vacancies with new proposals. In particular, the package is meant for strengthening existing legislation frameworks spanning various policy areas and economic sectors, reducing emissions for a broad range of fields, boosting targets for natural carbon sinks, keeping up to date with the emission trading system (ETS), as well as increasing investments dedicated to green transition and support citizens in facing the changes that the future holds.

The vision of the European Union with these concrete actions is to provide EU citizens with better information, options, and incentives to increase the possibilities for individuals to make a meaningful impact.

Every proposal part of the package follows the classic standard procedure for EU regulations:

- The European Commission presents the proposals included in the fit for 55 package
- The proposal is consequently sent to:
    - Council of the European Union
    - European Parliament
- Technical discussions are held by by the representatives of the 27 Member States
- The document is prepared for the meeting of ministers
- Council meeting of the ministers of the 27 states is held, with the "fit for 55" proposals discussed in several council formations
- Start of the trilogue:
    - Representatives from the three EU institutions reach an agreement through a joint vision of the proposals.
- Once an agreement is reached, the proposal is ready to become law, applicable to all Member States.

The package is comprised of 15 different proposals, each targeting a precise necessity for the climatic future of the Union:

- Reform of the EU ETS: strengthening the already existing procedure, by making it more ambitious and including numerous more provisions; developing a new self-standing emission trading system for buildings, road transport, and fuels.
- Social climate fund: addressing the social and distributional impact of new policies, providing support measures for the most vulnerable citizens, and tackling the risk of possible energy or mobility poverty arising from the extension of stricter policies.
- Carbon border adjustment mechanism: the aim is to ensure that the efforts made inside EU borders are not in vain and offset by increasing emissions abroad, targeting carbon-intensive industries.
- Regulation of land use, land-use change, and forestry: creates a commitment to increase natural carbon sinks as well as decrease emissions from the land use and forestry sector, with more ambitious provisions.
- Effort sharing regulation: binding every Member State to emissions' reduction targets in sectors that are not covered by the EU ETS or regulation on land use, land-use change and forestry (LULUCF).
- CO_2 emissions' standards for cars and vans: introducing a progressive EU-wide emission reduction target for cars and vans, with a 100% reduction target for 2035.

- Refuel aviation regulation: increasing the development and usage of sustainable aviation fuels reducing aircraft emissions.
- Fuel EU maritime regulation: decreasing the GHG intensity for energy on board up to 80% by 2050, promoting the use of low-carbon and sustainable fuels.
- The regulation of alternative fuels infrastructure guarantees citizens increased access to adequate networks able to recharge and refuel road vehicles and ships with alternative and low-carbon fuels.
- Renewable energy directive: as mentioned in the previous paragraph, the deployment of renewable energy is a key component of the energy future of the Union; with this regulation, the target is increased to a 40% renewable energy generation in the EU mix by 2030.
- Energy efficiency directive: to reduce EU-level energy consumption by almost 12%, increasing energy efficiency all over the Union.
- Energy performance of buildings: increase energy efficiency for buildings, reaching 100% of net zero buildings by 2050 and making all new buildings net zero by 2030.
- Revision of the energy taxation directive: aligning the taxation with the most up-to-date policies as well as preserving and improving the EU internal market.
- Hydrogen and decarbonised gas: to shift from natural gas to renewable and low-carbon gasses, boosting their uptake by 2030 and creating a regulatory framework dedicated to hydrogen infrastructures and markets
- EU methane regulation for the energy sector: aiming to track and reduce methane emission in the energy sector, from its extraction and production to its distribution.

The package was presented shortly after the International Energy Agency released its net zero scenario creating a space for comparison between the two.
Similarities arise around the decarbonization process, removing the use of fossil fuels as much as possible for buildings, industry, and the transport sector.
Further comparisons show the differences between the two, as the EU package revolves around the development of renewable energy and offsetting negative social impacts of the transition while incrementing the role of carbon pricing, as mentioned above. On the other hand, the IEA focuses on the implementation of a global carbon pricing mechanism characterized by increased stringency for what regards over-developed economies, with fewer indications about social implications involved in the transition.
The main reason for such differences can be attributed to the more global perspective the IEA is dealing with, looking into developed and developing regions where access to energy takes precedence over other considerations. An implied preference towards more nature-based sinks and elimination approaches is shown by the European Commission with an unclear position over the presence of carbon capture and storage.

5.2 Regulation of methane reduction in the energy sector

For this document, the most interesting segment of the fit for the 55 package is the regulation dealing with the reduction of methane emissions in the energy sector, which has been approved June 13th 2024 and will come into effect August 4th 2024.

The regulation lays down rules for the accurate measurement, quantification, monitoring, reporting, and verification of methane emissions in the energy sector, including their abatement via leak detection and repair, repair obligations, and limitation of venting or flaring events, increasing the transparency on the matter.

The regulation applies to different sources of methane emissions in the energy sector:

- Oil and fossil gas exploration and extraction facilities
- Natural gas transmission and distribution networks, excluding metering stations placed inside final customers' belongings, as well as underground storage and liquefied natural gas terminals
- Operating closed and abandoned underground coal mines
- Inactive, temporarily plugged, permanently plugged, and abandoned wells.

Revolving around three main pillars:

- Measuring and reporting:
    - Requirements to measure, report, and verify methane emissions in the energy sector.
    - Independent verifiers check all measurements.
    - Regular monitoring of equipment and networks
    - Public inventories for inactive wells and coal mines.
- Reducing emissions:
    - Immediate reduction through leak detection and repair, limiting venting and flaring actions.
    - State-level mitigation plans
    - Emissions decrease for abandoned extraction sites.
- Tackling energy imports:
    - Global monitoring tools to ensure transparency.
    - Trace emissions of energy imports.

The regulation includes the expenses sustained by operators; the competent authorities of each State must equally take into account these costs when fixing or approving tariffs, so as to internalize the expenditures and investments made to comply with the obligations set by the regulation.

Every Member State is expected to designate competent authorities, monitor and enforce an adequate implementation of the regulation, ensure compliance and cooperation within the Union as well as transparent information. Moreover, authorities must stay on top of inspections, with site checks and field audits, to ensure all frameworks are correctly followed and respected.

The conformity of the emissions reports has to be verified by verifiers accredited by a national accreditation body, according to regulation (EC) No 765/2008, which has to review all data sources used to assess the reliability, credibility, and accuracy of all emissions reports.

The regulation uses as a technical backbone the information provided by the International Methane Emission Observatory (IMEO) as well as the Oil and Gas Methane Partnership (OGMP).

5.2.1 Articles 12 - 13 - 14

Contained within the regulation, the articles that mostly affect the stage of the distribution of methane are article 12, concerning monitoring and reporting, article 13, about general mitigation obligations and article 14, dealing with leak detection and repair, which is also linked to Annex I where the frequencies of the surveys are set.

Article 12 sets all the standards regarding the communication and the reporting of methane emissions-related data, for all assets.

Operators are requested to quantificate the emissions from their assets, which estimated through three precise methodologies:

- Source-level methane emissions using at least generic emissions factors from all sources.
- Direct source level methane emissions.
- Site-level methane emissions.

While source-level measurements are directly undertaken with the use of a specific measuring device, site-level quantifications provide a complete overview of all site-level methane emissions, typically by using mobile sensors or other means such as fixed sensors or continuous point sensor networks.

The reports have to be verified by an accredited verifier and provide a comparison between the results obtained by the source-level and the site-level measurements; if there happen to be discrepancies between the results, the operators shall notify the competent authorities and carry out reconciliation processes addressing possible reasons for the divergence.

Article 13 is a very short one and it states "Operators shall take all appropriate mitigation measures to prevent and minimize methane emissions in their operations." which requests maximum mitigation efforts by all operators.

Article 14 sets up two different leak detection surveys to be performed:

- Type 1, a lighter survey, built around higher emissions thresholds made to acknowledge bigger leaks, is programmed to happen with a more frequent schedule and higher emissions threshold.
- Type 2, is a more in-depth leak detection survey with lower thresholds, whose goal is to intercept smaller leaks, programmed with a less frequent scale but able to ensure total safety for what regards environmental damages.

As described, the two types of surveys differ from each other in relation to their frequency rate, depending on the source of the emissions they are surveying; other important factors are materials that are known to have a major leak emission factor, for example, grey cast iron would need to be checked more often for sources that showed higher level of containment of methane emissions. Components of the network also present different schedules with pressure stations and regulating and metering stations surveyed more often than valve stations.

Scheduling changes also with the different pressures the natural gas is managed, as the higher the pressure is the higher the chances for a leak to have a high flow on the atmosphere.

Components found to be emitting methane above the thresholds set by the different survey types:

- During type 1 surveys there are no differences in how the leak is perceived and measured, and the threshold of the volume flow of methane is 17 g/h.
- Type 2 surveys, on the other hand, have different thresholds depending on where and how the leak is found:
    - 1 g/h for aboveground components.
    - 5 g/h for underground components at the closest point reached for the measurement.

The survey for underground components is trickier, as it is divided into different steps: the first step consists in measuring at the interface between ground and atmosphere, where the leak is detected; the second step involves a further measurement, as close as possible to the emission source.

In relation to repair measures and times, major changes are expected; mainly, repairs and replacements of components found to be emitting methane must take place immediately after the detection.
In the occasion of impossible immediate repair, once the leak is found the maximum amount of time for the delay of the repair is 5 days, with a completion time of 30 days; however, when an operator can demonstrate that a repair is not feasible in the 5 days and/or the operator does not expect to finish the complete repair actions due to technical, safety or administrative concerns, this has to be notified to competent authorities along with the proof for the excessive delay.
During the delay period the minimization of environmental impacts has to be ensured, as said in Art. 13, respecting all safety, administrative, and technical requirements, such as safety procedures of personnel and other persons in the proximity of the leak, the accessibility of a component or any bureaucratic requirement or authorization as well as the unavailability of replacement parts needed for the repair.
One possible case is that of the negative net environmental impact of the repair: this occurs when a repair would bring about a higher environmental impact than benefit; for example, when a repair leads to a higher flow of methane emissions. In this situation, a required shutdown is mandated, before the repair or replacements, so that operators can minimize the leak in the following 24 hours and repair it by the end of the next scheduled shutdown or within a year, choosing the earliest of the two options.
Notwithstanding the previous surveys, operators are expected to perform further checks on components that, during previous surveys, were found to be emitting levels of methane equal to or higher than the aforementioned thresholds, so as to ensure the repair was successful; in addition to that, leaks that were found to emit a lower amount of methane than the thresholds also require re-checks to assess if the leak increased in its size and if replacement and repair are needed.
Leak detection and repair reporting will also be a key component as operators have to create a database for leaks for 10 years, to keep track of them and regularly survey ensuring their correct repair. Every year operators shall also submit all repair and monitoring schedules as well as a report containing all LDAR surveys completed during the year.
All LDAR operations can delegate the actions related to Chapter 15 of the regulation without being exempt from responsibilities and accountability related to such operations, LDAR service providers as well as operators will be ensured certifications and accreditations schemes, such as personnel training programs.

5.3 Environmental and economic analysis of European policies

The European Commission with the implementation of Regulation 2024/1787 *"Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on the reduction of methane emissions in the energy sector and amending Regulation (EU) 2019/942.",* aims to reduce the environmental impact of methane emissions within the whole energy sector; to achieve this, policies directly hitting the distribution of natural gas were developed, increasing leak detection,strengthening the stringency on leak elimination and improving monitoring reporting and verification processes.

Based on the different considerations that have been developed during the writing of this document, the EC Regulation will be examined to analyze the changes that it will bring onto tackling fugitive emissions, to ensure that the focus and the allocation of resources is optimal for abatement purposes.

The target of the analysis is to understand how the Commission decides to act, if with an increase in inspection rate or pathing towards a stricter elimination policy.

Interesting will be to detect if the Regulation follows the consideration made in chapter 4 of this document regarding mitigation strategies, by allocating more resources and stringency to the detection of leaks, with respect to the elimination of leaks.

At first the analysis will deal with the monitoring, report and verification, understanding how the Regulation intends to solve the lack of reliable information that as of now characterizes the environmental reporting, examining the improvements brought by Regulation 1787.

The following paragraph will be divided into two segments, with the first one 5.3.1 dealing with leak detection economic analysis, to examine how the Regulation acts regarding leak detection, by granting resources or enhancing citizen engagement or both, while the second part, 5.3.2 will dive into the leak repair procedures analyzing the changes resulting from the Regulation, examining the impact and the possible costs of such changes.

Each section will analyze the articles and the commas responsible and dedicated to each activity of the leak detection and repair (LDAR) actions required by the Regulation, understanding the environmental and economic impact of every change generated by the European Commission's decisions. The Regulation results will be compared with the status quo to examine which areas have been targeted and which have not, analyzing if the changes are strong enough to make a visible difference in emissions abatement.

It is important for the reader to know that the Regulation states that the investments that the companies will face in the actions required to comply to the changes brought will be taken into account in tariff setting, subject to efficiency principles[112].

The end of paragraph 5.3.4 will outline all the considerations that arise from the analysis, focussing on the Regulation performances on resource allocations as well as on policy efficiency.

[112] Regulation (EU) 2024/1787 of the European Parliament and of the Council of 13 June 2024 on the reduction of methane emissions in the energy sector and amending Regulation (EU) 2019/942, preamble (10)

5.3.1 Reporting, monitoring and verification

Regulation 1787 asks companies to provide both source-level and site-level emission estimates for all sources which compose the company's network, with detailed data regarding every source and estimates expressed both in tonnes of methane and tonnes of carbon dioxide equivalent, using IPCC global warming potential, also expressing quantification methods and the quotas of emissions the company is responsible for both managed and non managed assets.
This first report will be a first benchmark in order to understand the current situation companies face and it has to be verified by a verifier registered in the European Union.
Currently reporting, monitoring and verification does not happen for environmental purposes as companies have no such requirements, meaning that not all companies have familiarity with the required procedures.
The lack of skills related to environmental reporting could increase the chance for possible rises in costs for compliance of article 12, mainly due to the hire of new professional figures or due to consultancy services required for norm compliance; on the other hand companies that are already used to environmental reporting might be able to face these new requirements with lower costs attached.
Related costs should not be too high since reporters could pair up with already practiced operators during the inspections and use already planned inspections as baseline for reporting duties, inspections that will be increased by the regulation in frequency and stringency.
The compliance to this regulation will create a general knowledge about the current status of the methane emissions, increasing the efficiency of following policies targeting the issue.
The verification process, although expensive, is needed to ensure the reliability of the estimates: as of now companies individually verify their estimates, which can be drastically unreliable since companies might not follow right estimates practices resulting in missestimations or intentionally ignoring sources to meet environmental KPIs.
The reports have to be done on a yearly basis combining the source-level emissions estimation report to the site-level emissions estimation report, comparing the two and assessing their similarities, checking on any evident statistical discrepancy, preparing a reconciliation process addressing possible reasons for the discrepancies, including accuracy and appropriateness of the methodologies and the technology used, considering additional source-level quantification or site-level measurements to provide necessary evidence to explain the possible reasons of the discrepancies, and based on the reconciliation process operators should implement adjustments to quantifications and measurements.
It will be interesting to understand how companies will face such requirements, deciding either to internalize the compliance processes, developing the needed professionals figures in-house or outsourcing them from third parties; these decisions will also shape the costs of such change in reporting since better structured companies will be able to find personnel inside while smaller companies will be forced to pay third party companies to help them comply with the new regulations's requirements.
By requiring data regarding environmental performances, the Regulation uncovers the reporting fog that has been surrounding the natural gas distribution sector, giving the possibilities to steeply decrease emission estimation uncertainties that will eventually increase the efficiency of future mitigation action and policies.

5.3.2 Leak detection environmental and economic analysis

Article 14 of the Regulation 2024/1787 deals with the procedures for the leak detection and repair (LDAR) implementing a first programme for leak detection and repair including details regarding surveys and activities.
The Regulation proposes two different levels for LDAR surveying, type 1 and type 2, characterized by the different threshold limits for repair and inspection frequency.
Type 1 LDAR have higher frequency requirements but are not as stringent with repair thresholds with the aim to find bigger leaks with more consistency; while type 2 LDAR have a lower frequency but smaller threshold for the leaks encountered, as the aim is to find those smaller leaks that were not spotted by the type 1 LDAR.
Type 1 LDAR is set to be performed only on components and networks distributing natural gas at a very high pressure (>16 bars), while on the other hand type 2 LDAR has to be performed on all kind of designed pressures caring for high, medium and low pressure, thus actually covering the whole distributing network.
In light of this difference, the only leak detection and repair type that will affect the distribution of natural gas is type 2 since all distribution networks are managed at pressures that are well below 16 bars, but, for the sake of the document, type 1 will be also covered.
The natural gas flow thresholds for leak repair are set on a lower level with respect to the emission factors used in this document for the estimation, at least for what regards undergrounds and aboveground leaks.
As mentioned above, type 1 LDAR limits for interventions are higher, evaluated at 17 grams for every hour, which correspond to 0,025 standard cubic meters (scm/h) of methane per hour released.
Since the Regulation limits the emission factors in grams per hours, the calculation used to translate the mass flow to volume flow is the inverse of equation (3):

$$Q_v = Q_m/\rho_{ch4} \qquad (3)$$

The same calculations are needed for the thresholds of type 2 LDAR surveys which differ between aboveground and underground components, as aboveground leaks have a limit of 1 gram of methane leaked every hour and underground 5 grams per hour, which results to respectively 0,0015 smc/h for aboveground leaks and 0,0076 scm/h for underground leaks.
These thresholds are expected to undoubtedly decrease the overall emissions by steeply increasing efforts dedicated to limiting the flow of emissions.
This would be the actual first time methane emissions are targeted based on their impact on the environment, expressed by the mass emitted every hour, and not due to the danger posed by the potential explosive threat of methane leaks in closed environments, expressed by the concentration of methane in a specific place, revolutionizing the approach companies have always had when dealing with fugitive emissions.
Companies will have to acquire new tools in addition to those they already possess in order to deploy trustworthy source-level measurements, educating the current personnel on measurement methodologies and on the correct procedures to follow, in order to deal with the uncertainty of such measurements.
Measurements of this entity might be endangered by weather and soil conditions, as both iced and wet surfaces are not easy to inspect due to the impermeability given by the frozen soil and the absorption phenomenon given by humid or wet terrain.

Moreover current measurements are already made impossible by the presence of wind since with wind capable of moving sheets of paper and small branches, comparable to the level 4 of the Beaufort scale[113] (20 km/h - 28 km/h), the measurements cannot be performed.
Increasing the precision required by the measurements will increase the margin of uncertainty, and the effects of weather agents; hence, more precise sensors that can provide trustworthy measurements even in difficult conditions are essential.
The regulation will therefore have an impact on the demand for components required for devices and machinery as well, since the demand for the tools designed for the accurate inspections, capable of functioning under severe weather conditions, can be expected to rise.
As of now, while the flow thresholds to eliminate a leak have been declared, the detection techniques to be employed for the different detection devices remain an objective for the future since the Commission has until august 2025 to specify the values and specific procedures.
As previously mentioned in this chapter, the different types of LDAR will have different frequencies with LDAR of type 1 having a higher frequency over the year while type 2 has a more scattered frequency, due to the increased precision of the surveys.
The regulation norms the frequencies of inspections by dividing them in two groups, components and materials, as every component and every material are required to be inspected with a certain specific frequency, differently to the current procedure where the inspections use only materials as a frequency factor.
It is possible for companies to only perform type 2 LDAR, instead of double inspecting by carrying out type 1[114] LDAR as well.
Let's go back to table 6 where the inspections performed by the company were compared to the current mandatory Italian inspections, and compare them to the changes made by the EU Commission. The new regulation changes the methodology, eliminating the pressure factor by equalizing all designed pressures and focussing only on the materials of which the pipelines are composed of and the components that might be source of emissions. Regulating and metering stations following type 2 LDAR directives have to be surveyed every 9 months, while all valve stations have an inspection time of 21 months.
Type 2 LDAR survey on pipelines with designed pressure under 16 bars, as aforementioned, have different standards, starting from gray cast iron and bitumen pipelines with a 6 months survey required time, asbestos and ductile cast iron every 12 months, non protected steel and copper every 24 months and polyethylene, PVC and protected steel every 36 months. The new standards require higher effort with respect to the previous Italian standards but do not differ too much from Company's performances in network inspection, hence the extra costs imposed by the increased strictness of the regulation could be neglected, assuming that the costs the company has right now would not increase severely with the application of the new inspection frequency. As a matter of fact most of the low-pressure network managed (>90%) is already composed by protected-steel or polyethylene pipelines, thus the standards align and the chance of a rise in costs for inspections are slim.

[113] *World Meteorological Organization. Commission for Maritime Meteorology. The Beaufort Scale of Wind Force : (Technical and Operational Aspects). Geneva :WMO, 1970.*
[114] EC Regulation 2024/1787 art. 14.3

Material	Eu regulation standards
Grey cast iron Bitumen sheet	6 months
Asbestos Ductile cast iron	12 months
Non-protected steel Copper	24 months
Polyethylene PVC Protected steel	36 months
Regulating and metering station	9 months
Valve station	21 months

Notes: The table shows the type 2 LDAR inspection frequencies for what regards pipeline materials and components required to comply with Regulation 202/1787

Table 88 *Type 2 LDAR inspection frequency*

The most significant changes brought by Regulation 2024/1787 are related to network components inspections which, from now on will be part of the inspections plans with different frequency based on the different operating pressure. The Company's high pressure regulating and metering stations (cabine REMI) in 2022 were 115 and are the stations that receive natural gas from the transportation network, reducing it to a pressure low enough to ensure a correct jump from transport to distribution.
REMI's stations are only a small percentage of the company's regulating stations as there are also stations working with lower pressurized natural gas, or Impianto di Riduzione Intermedio (IRI), and low pressurized natural gas, or Gruppo di Riduzione Finale (GRF), which are paired due to their similarities.

Since all the stations work under a pressure lower than 16 bars they are only subjected to type 2 LDAR procedures, without the requirement of any type 1 survey.

	REMI	GRF/IRI	Total
2022	115	3.036	3.151
2021	116	3.049	3.165
2020	116	3.050	3.166
2019	111	2.929	3.040
2018	110	2.921	3.031

Notes: The table shows the number of regulating station divides in REMI cabins and GRF/IRI cabins, for every year that has been examined in the document

Table 89 *Regulating and metering station number*

The metering and regulating stations, following the methodologies suggested in Regulation 1787 require the same inspection frequency, which is set to every 9 months, about 273 days.
That would translate in an inspection rate of 11,5 metering and regulating stations every day, if the number of stations remains the same as 2022.
This means that, with good probability, a team would be dedicated only to that precise operation, or Companies will need to figure out how to include the surveys to their already planned network inspections in order to increase the efficiency during the planning, implementing practices that internalize the metering station surveys in their current inspection routine enabling time optimization, prioritizing accurate analysis and measurements.
Networks inspections analysis exhibits a slight difference between the Italian regulation, Delibera 569/19 and the European Commission regulation, Regulation 2024/1787: regarding the network managed by the Company taken in exam, the kilometers to inspect for every month, as of 2022 data, would change from 493 km inspected every month, as according to the Italian regulation, to 510 km inspected every month under the new European regulation.

Year	Delibera 569/19	Regulation 2024/1787	Company inspection performances
2022	493	510	737
2021	493	513	695
2020	493	514	655
2019	477	486	632
2018	476	487	636

Notes: The table shows the monthly kilometers inspection required by different compliances: Arera's Delibera 569/19 (Italian regulation), Regulation 2024/1787 (European Union regulation) and the current Company performances, expressed in kilometers every month

Table 90 *Monthly kilometers inspection rate*

Table 88 shows how the different normative setups would have affected monthly inspections for every year analyzed, exhibiting an increase over the years and higher values for the monthly kilometers under the newly approved EU Commission regulation.

Assuming the time spent inspecting every kilometer under Delibera 569/19 is the same as under the Regulation 2024/1787, the company standard covers the increase caused by the new norms as of2022 data because it already surveys slightly more than 700 km every month.
With these estimates, it is possible to assume that the inspection costs would not rise sharply for distribution companies, but it mostly depends on their performances before the EU Commission's regulation takes effect.
From the estimates above, Regulation 1787 will not result in a decrease in estimated emissions related to the reduction in latency time, signaling a lack of stringency and showing little to no embittering of the current Italian requirements, only increasing the inspection rate of a mere 4%.
The Regulation lacks in stringency, failing to improve methane abatement strategies in the pre-localization of leaks, as Companies, at least in the Italian distribution sector, will not need to invest in inspections; this translates in stagnancy for what could regard technological advancements and efficiency improvements, keeping the current situation reliant on physical labour, since there is no need for them to change.
On the other hand, lower detection thresholds might result in a higher number of leaks located; these, however, will not be voluminous leaks in terms of emissions, since the limits are set on levels that are much lower than the emission factors used in this document for emission estimation.
Paradoxically enough, the aforementioned increase in detected leaks could lead to time inefficiencies during inspections: granted that a higher inspection rate translates to leaks being discovered quicker instead of remaining unnoticed for longer periods of time, it is equally possible that, to comply to the new, more precise limits and thresholds for detection, extra time surveying the network is needed.
The additional time that would be required for in depth and accurate measurements does ultimately translate to further time and labor asked of the inspecting personnel, and this is, as shown previously in the document, directly correlated to inspection costs. This possible aspect of inefficiency is the reason why technological research and improvement of leak detection techniques are key and vital aspects for a successful implementation of the Regulation and similar norms: investing in technology means decreasing detection time, reducing the cost of inspections and detection procedures and, ultimately, enhancing efficiency.
One cannot overlook the fact that technology faces its own set of challenges: harsh weather conditions, such as wind speed and wet soil, paired with the increasing demand for more precise inspections, could lead to an overall difficulty in carrying out the inspections, postponing and delaying surveys and increasing the time needed to assess the network. However, while these problems do affect the operational stress and decrease the exploitable time for surveys, they do not alter the costs: this is because, if technology is efficiently deployed, it is not required for operators to work more, or to even work on the inspections when the conditions are not sufficiently optimal.
The remaining problems could be partially solved by switching to pressuring and regulating stations, switching from outdoor surveys to indoor inspections, decreasing the time wasted due to weather conditions, hence increasing the efficiency of the inspecting operations which is also connected to operational costs and expenses.
The effect of the Regulation in technology investments is ambiguous, from the inspection point of view companies are not encouraged to invest since there is no need for performance enhancement; while from the detection side, the lower detection limits will force companies to invest in equipment able to detect under the new thresholds.

5.3.3 Leak repair environmental and economic analysis

The current methodology for leak detection depends on the volume of methane located in a certain space which triggers around the lower flammable limit (LFL), already mentioned in the document, which is the lower end of the concentration range for a specific flammable gas, expressed by the percentage of gas needed in the air for ignite at normal temperature and pressure, which for methane is 5.0% (ISO10156).

Regulation 2024/1787 abandons these detection techniques, by moving towards the measurement of the flow of methane leaking with limits that, as shown earlier, are even lower than the emission factors used for estimations.

It is important to underline that, with this switch of practices, the number of leaks used for estimates will not decrease: all leaks located with the LFL method are as equally detectable with the method introduced by the Regulation.

Not only does the number of detected leaks not decrease, but it actually rises due to many fugitive leaks, that were previously not deemed as requiring repair, becoming instead targeted by the Regulation because the newly proposed limits for intervention include them in the repair programs.

Such increase would have a positive impact on detection and repair costs, increasing them due to the higher number of leaks that would eventually translate to a rise in time spent both inspecting and repairing leading to a coherent growth of personnel expenses.

Since these further costs are the result of assumptions, it is not possible to estimate due to missing data, which will be available soon in the future, once the regulation starts to produce effects.

Once the companies can start gathering data and initial reports begin to emerge, it will become possible to analyze if the decrease in limits and thresholds for repairs did in fact increase the overall number of leaks found during surveys, as well as their emission flow.

The number of emissions rising due to the Regulation does not mean that there are more emissions occurring: the value increasing is due to the fact that there are more emissions that are now detected, because at the current state there are emissions happening that remain undocumented, meaning that the methane is leaking but it remains unaccounted for by companies and regulators because they do not pose a danger to people and goods.

These lower limits will interact with ISO 15848-1, which is the main standard for valve type test for shut-off valves and control valves when it comes to tightness performance. The standards' higher value, of class C, has a leak rate of 500, part per million (PPM) which is equal to the value limit expressed by Regulation 1787 for above ground leaks, meaning that components complying with the ISO 15848-1 class C would be, by default, responsible for leaks that have to be repaired, but with the impossibility for the repairment since the valves have that leak level by design.

The result will force either the standard to change or companies to invest in valves that exceed the class C in order to not run into similar problems, further decreasing the chances for fugitive emissions related to leaking components.

Investments in components compliant with at least class B, which on the other hand has a maximum leak rate of 100 part per million, a level lower than any of Regulation 2024/1787 minimum elimination levels, will increase costs for distribution companies which will have to add on the costs related to the inspection and tools compliance also the components compliance, which for companies relying with old networks would mean a steep increase of early expenses related to the entry in force of the Regulation.

Such costs are impossible to track down since information regarding of the network, that is not in possession, would be needed; moreover,such components do not have fixed prices but vary in size and load, making such costs only theoretical, but they remain costs companies must be aware of when transitioning under the new norm.

Regulation 2024/1787 will also affect the delay time related to the elimination of leaks found during network inspections; article 14, in fact, expresses the modalities of approach to leak elimination that distribution companies have to follow to comply with the regulation.
As previously explained in the document, see paragraph 5.2.1, components found to be leaking must be repaired immediately after the detection. If this is not possible, the first attempt may be postponed by a maximum of 5 days, and the final leak elimination has to be completed within 30 days. Exceptions can be made if an operator is able to demonstrate the impossibility of repair or replacements within 5 days as a first attempt or 30 days for the complete procedure due to safety, administrative or technical reasons.
Differently to how it has been done in the past, the operators will have to prioritize repairing larger leaks.
The Regulation will not completely change the current approach to dangerous leaks, as the prioritization regarding leaks that as off now are considered of immediate priority will still be implemented and leaks of A1 priority will still be eliminated with the priority that they currently under , forcing the companies to intervene in a maximum of 24 hours.
The resulting situation will be one where companies will have to decrease the overall delay of leak elimination, starting all leak elimination procedures in a 5 day frame and completing them in maximum 30 days, while still treating possibly dangerous leaks with the priority they have been treated by the Italian regulation.
Regulation 1787 does not cover all leaks previously covered by Delibera 569/19, as leaks arising from metering stations located inside private spaces do not follow the schedules and the timing expressed by Regulation 1787, and will still be covered by the local norms.
National norms are finalized for the safety and continuity of the service, hence are often stricter than the environmental requests of the Regulation, and cover a much broader range of leaks, as the duty to intervene on private properties, gas meter and post gas meter installations is not explicit in the European regulation.
The decrease in the time allowed for leak elimination will certainly reduce the amount of emission deriving from the scheduling phase of a leak's existence, since the flow of methane will last for less time, decreasing the overall amount of methane released. The cost of such methane abatement measures will reflect in an increase in operational pressure, since the time given to companies to structure and organize elimination personnel will be reduced, making elimination scheduling more difficult, and increasing the chances that multiple elimination operations happen at the same time, expanding the number of operational teams that are needed at the same time and increasing the need for operational figures then increasing personnel costs.
The analysis of the environmental impact will be performed by comparing the estimated emissions with the current Company performances:

- It will be performed on elimination time estimations
- Gas meters leaks will be kept as they are currently since they are not accounted for in Regulation 1787
- Elimination time will have a cap set a 30 days, equal to 720 hours

The results of the following estimation will then be compared to the current Company estimated emissions with the aim to value the estimated benefits the regulation will bring about in terms of emissions abatement as well as the possible costs that could arise by deploying such measures.

Volume	Regulation 1787 post-localization estimated emissions - Methane m^3				
	Aboveground	Gas meter	Components	Pipelines	Total
2018	3.487,29	215,59	28.497,00	57.051,64	89.251,53
2019	2.898,10	29,95	37.044,31	73.364,83	113.337,19
2020	5.316,00	25,53	42.395,54	71.101,97	118.839,04
2021	7.958,85	30,03	35.317,79	71.739,95	115.046,62
2022	3.711,17	6,94	35.439,51	69.966,35	109.123,97
Total	23.371,41	308,05	178.694,16	343.224,74	545.598,35

Notes: The table shows the estimated emissions arising from the changes in scheduling times brought by Regulation 1787 expressed as cubic meters of methane, divided by leak source

Table 91 *Regulation 1787 post-localization estimated emissions*

Table 46 represents the estimated methane emissions that would have arised if, during the years taken into consideration in this document, the Company had repaired leaks in the timeframe required by Regulation 1787.

The second step will be to compare those two performance tables (table 46 and table 12) with an attentive eye on the values that change. Given that the changes brought about by Regulation 1787 concern the allowed leak elimination time, major changes will mainly be seen for those sources that allow a higher elimination time, thus those that exceed the new EU limits of 30 days.

By doing so the Regulation cancels out the class C of the Italian prioritization system by eliminating the delay on repair caused by the low priority class C leaks have under Delibera 569/19.

Better results insights can be obtained by comparing table 46 to table 12, which exhibits current results for the same time.

Company post localization estimated emissions - Methane m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	3.487,29	215,59	35.977,21	72.100,20	111.780,30
2019	2.898,10	29,95	51.295,93	96.897,92	151.121,90
2020	5.316,00	25,53	46.580,41	78.105,02	130.026,96
2021	7.958,85	30,03	40.480,41	77.455,33	125.924,61
2022	3.711,17	6,94	53.443,14	93.053,69	150.214,94
Total	23.371,41	308,05	227.777,09	417.612,17	669.068,72

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by priority classes: Immediate priority (A1), High priority (A2), Medium priority (B) and low priority (C).

Table 23 *Post-localization estimated emissions*

Table 23 expresses the current estimation values for Company emissions and, it is already noticeable that the difference in overall emissions matured over the years examined, especially in underground leaks.

Post localization estimated emissions difference - Methane m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	0,00	0,00	-7.480,21	-15.048,56	-22.528,76
2019	0,00	0,00	-14.251,62	-23.533,09	-37.784,71
2020	0,00	0,00	-4.184,87	-7.003,05	-11.187,92
2021	0,00	0,00	-5.162,62	-5.715,38	-10.878,00
2022	0,00	0,00	-18.003,63	-23.087,34	-41.090,97
Total	0,00	0,01	-49.082,94	-74.387,42	-123.470,36

Notes: The table shows the estimated emissions difference that arises from the comparison between current Company performances and the performances generated by the changes brought by Regulation 1787

Table 92 *Post-localization estimated emissions difference*

As assumed before, the changes impact only underground leaks, as they are the ones currently exceeding the 30 days limit that will be imposed by the Regulation.
By doing so it is possible to estimate a yearly average of emission decrease of roughly 24.600 m^3 of methane every year, that add up to 123.470,36 m^3 of methane abated.
The estimated benefit for the policy, for what regards post-localization emissions, have been calculated following the same methods as before, by pricing the natural gas loss as an economic loss and the equivalent methane emissions as environmental externalities.

	Unit cost	**Emission difference**	**Benefit**
Economic benefit	€ 0,50	134.206	€ 67.103
Environmental benefit	€ 1,83	123.470	€ 225.950

Notes: The table shows the different benefits that arise from the change in Regulation, the first row shows the economic benefits:
first column: the cost per unit expressed in euros per standard cubic meter of natural gas emitted; second column: natural gas emissions abated by the change in prioritization expressed in standard cubic meters of natural gas; the third column economic benefit related to the abated natural gas emissions resulting by the multiplication of the unit cost for the emissions abated. The second row shows the environmental benefits: first column: the unit cost expressed in euros per cubic meter of methane emitted; second column: methane emission abated by the change in prioritization expressed in cubic meters of methane; third column: environmental benefit related to the abated methane emissions resulting from the multiplication of the unit time and the abated methane emissions expressed in euros.

Table 93 *Regulation 1787 post-localization benefits*

The values expressed in table 93 are the monetary benefits arising from the change that the Regulation brings in leak elimination.

The economic benefit reflects the cost that the decrease in natural gas losses brings to the market, which is equal to the market cost of the recovered natural gas, while the environmental benefit is intended as the externality connected with the greenhouse gas potential of methane and reflects the abatement of methane in the atmosphere.
The sum of the two reflect the total social benefits that the changes would bring to society.

Economic benefit	**Environmental benefit**	**Social benefit**
€ 67.105	€ 225.950	€ 293.053

Notes: The table shows the different benefits arising from the changes in Regulation of leak elimination, expressed in euros.

Table 94 *Regulation 1787 benefits*

The benefits come at a cost, as the decrease in leak elimination will need investments.
Cost estimation is not straightforward, but since the leaks affected by the measure are located only underground it is possible to assume that the rise in costs could be significant, if compared to a fictional increase in aboveground leak elimination costs.
The increase in costs is not of possible estimation with the data in hand, since it depends on multiple factors, mostly on the abilities of the Company to still schedule efficient leak repair and on the timing of the leaks.
The decrease in scheduling time will result in higher operational pressure, since there is a higher chance that several leaks have to be eliminated simultaneously, hence increasing the costs related tot the deployment of an increased number of operational personnel.
From the analysis previously done in the document it is possible to assume that the costs related to the elimination time decrease described by the Regulation will not be efficient and will not be covered solely by the economic benefit generated by the abatement, resulting in an inefficient investment.

5.4 Stranded assets and decarbonization policies

Decarbonization policies could have another effect on all companies in the industry increasing the risk for such companies to develop stranded assets. By definition a stranded asset is an asset that has suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities. This often occurs due to changes in regulation, market conditions, environmental factors, or technological shifts that make the asset no longer economically viable.

Natural gas distribution systems include the infrastructure used to deliver gas from the transmission pipeline to end users, including pipelines, compressor stations, metering and regulating stations an service lines. These systems become stranded assets when they can no longer deliver a return on investment due to economic, regulatory or societal changes, such as a change in demand.

Up until now, the document presented well documented reasons why such changes might be in place in the near future, as policies around decarbonization are strengthening and the targets are becoming more and more ambitious.

Government climate goals are mandating rapid shifts towards renewal electricity generation and hydrogen with different projects on their way to be completed[115].

The following growth in electrification technologies, replacing natural gas heating-generated systems, i.e heat pumps and electric stoves, reduces the need for gas in homes and businesses as well as the increase in the use of battery storage and renewable microgrids that would offer viable off-grid or low-carbon alternatives, making gas unnecessary locally.

With electrification being more common and cost-effective, more users might electrify their energy supply. This would leave fewer customers left to share the cost of maintaining the gas system increasing the economic unsustainability of the market, in what has been called a death spiral scenario. In addition to this, aging infrastructures will require increasing operating costs making them less attractive to investments in upgrades and maintenance.

Eventually, investors may consider long-lived gas infrastructures as high risks, leading to reduced access to capital or increased borrowing costs[116]. The financial implications might resolve in utilities and investors facing billions in unrecoverable costs, with regulators that may not allow cost recovery from ratepayers for assets no longer providing service. This situation is exacerbated by the clear mismatch between infrastructure lifespan and the timeline for decarbonization. While gas infrastructure typically requires 30 to 60 years to generate returns, policymakers are pushing for transformative changes on a much shorter timeline, often targeting milestones in 2030 and 2050.

Historical precedent can shed light on the risk of asset stranding, For example, the early retirement of coal-fired power plants in western europe[117] due to carbon pricing and renewable subsidies caused major write-downs in utility portfolios. Similarly, but on the opposite level, the abrupt phase out of nuclear energy in Germany left several investments stranded[118]. These cases suggest that even well established assets can become obsolete within a decade when policies or political sentiment shift abruptly.

The degree of vulnerability to stranding varies by region, where in jurisdictions with aggressive electrification and sustainable policies, as Europe, gas distribution systems are under immediate pressure. Urban areas with high building density and electric ready infrastructure may transition faster[119], whereas rural regions with fewer alternatives remain dependent on gas, complicating uniform policy implementation.

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[115] IdrogeMO, joint project between Hera and SNAM, financed by the Emilia Romagna region

[116] *Credite Agricole. Livre Blanc, 2023*

[117] Rentier et al (2019)

[118] Scherwath et al. (2020)

[119] IEA (2024)

Legal and regulatory risk is another growing concern. Emerging methane leakage, as well expressed along the text, and the connected regulations and finance rules could place additional burden on gas infrastructure. In the European Union, financial institutions are under increasing pressure to avoid investments in infrastructures deemed inconsistent with the European Taxonomy.
Stranding of assets also carries socioeconomic implications. Communities dependent on gas utility jobs may face economic disruption as the related job positions decrease in number and wage. Low-income households might be disproportionately affected if they are among the last users left on an aging and expensive network as the upfront cost for private electrification could leave them behind in the transition and rural areas, that are historically poorer than the cities might be hit harder.
Gas utilities are beginning, carried by the policies, to respond to these challenges by exploring strategic pivots in investments allocation. Some are investing in hydrogen (Hera and SNAM), or planning hybrid networks to maintain asset value, not without upfront capital expenses. Other are participating in district electrification pilot projects to position themselves in a decarbonized energy future. Innovations in rate design, such as performance based regulation or electrification incentives, are also being tested to align utility revenue models with climate goals.
Natural gas distribution systems face mounting risk from decarbonization policies, technological evolution, and changing consumer behavior. The financial, legal and social impacts of asset stranding are far-reaching, and will require coordinated action across regulators, utilities and communities to manage the transition smoothly and effectively.
Distribution companies find themselves in a situation where expensive interventions onto their systems might not operate enough to provide returns, limiting the investments to smaller operations that do not change drastically natural gas leaks.
It is also true that while on paper the European Union wants to decarbonize its economy by 2050, the path is still long as we have just peaked in 2021[120], previous to the Russian invasion of Ukraine that led Europe natural gas consumption to drop by 2% in just one year. The share of natural gas as primary energy in the European Union is still as high as 20% with the Italian contribution at 35%.
The ambiguity around fossil fuel phase out could make distribution companies approach the maintenance and leak management processes with low effort, granting only compliance with regulations, withholding companies from invest in greater values on methods that efficiently track and eliminate leaks, due to the higher investment that would be needed.

[120] Energy Institute - Statistical Review of World Energy (2024)

5.5 Considerations

The European Commission decided to intervene on methane emissions' reduction in the distribution sector in three different ways: creating a normative relative to monitoring reporting and verification, that previously was not covered by any norm, organizing network inspections by two different types of surveys, each with its precise schedule, and setting a time limit to leak elimination.
The creation of a regulatory framework on emissions monitoring and reporting is a much needed implementation and will help to create a database on methane emissions while at the same time allow the companies to increase their knowledge on their own networks.
The development of reliable emissions' inventories will decrease the uncertainty around estimations that will be backed by source data precisely measured by the companies and while this action will create a solid foundation for the future, the measures that directly affect leak detection and repair might create some ambiguity.
For what regards leak detection, Regulation 1787 lacks strictness only increasing the volume of network to be covered annually by 4% with respect to the current Italian normative, with a proposed mandatory schedule of inspection that however does not force the Company examined to increase the investments in such field, missing out on the most efficient method to counter emissions, as of the analysis previously assessed in the document.
While lacking on leak detection strength, the Regulation decreases detection limits, increasing the number of leaks deemed to be emitting as well as the costs of leak elimination; the measure however concerns leaks that account for values of methane lower than those used in this document as emissions factors, hence increasing inefficiency in resource allocation, since there will be an allocation of resources on low-impacting leaks.
With the same leak-elimination philosophy the regulation sets the time granted for leak elimination to 30 days, hence decreasing, with respect to the Italian regulation, the scheduling time for companies, actually eliminating C class prioritization for aboveground and underground leaks, as the Regulation does not cover gas meter leaks, which will still be covered by the current Italian regulation issued by Arera.
The measures will have a sure and positive impact on emission reduction, as estimations show that with such elimination time limit, there would be a decrease of about 25.000 m^3 of methane every year, with a related increase in elimination costs.
Companies on their hand will have to account for the possibility to have more leak elimination procedures performed at the same time, which would lead to an increase in costs related to operational pressure.
The lack of attention dedicated to leak detection is proven by the utter nonexistence of provisions regarding citizen engagement and possibilities for end consumers to participate in leak detection.
Regulation 1787, at its entry into force, will not have a decisive impact on decreasing emissions since the measures will not translate in a steep estimated emissions decrease, and the time phases hit by the changes do not provide much room for improvement from an Italian perspective.
The absence of citizen engagement penalizes potential progress in emission abatement, as the only effective measure in this regard is the Italian regulator economic transfer which, from an environmental point of view, fails to decrease emissions.
The position of the European Union is certainly not as strong as it could have been expected to be considering the target set within the packages and the proposals, but the fact that it has to account for all countries within the EU borders could explain the lack of stringency that has been shown in this review.

Harmonizing the same framework for every Member State is not an overnight job and requires investments and data. Companies able to adapt and develop environmental-friendly policies should be encouraged, while companies failing to do so have to be forced to change their course of action.
At the same time the regulator has to increase the efficiency in targeting emission, avoiding a waste of resources that will eventually translate into higher tariffs with little to no environmental benefits attached.

Chapter 6 - Conclusion: results, discussion and future work

Methane fugitive emissions represent a critical challenge in achieving global climate goals, particularly given the short-term impact of methane impact on global warming. Their abatement would grant quick responses, and the energy sector provides chances to achieve emissions reduction with the implementation of efficient and targeted policies, especially within the natural gas supply chain.

The thesis has addressed the research question: *how can policies be optimized to efficiently prevent and address fugitive methane emissions in the natural gas distribution phase?*, by exploring the Italian distribution network as case study.

Through a comprehensive analysis of data, methodologies, policy frameworks and practices the study's intention was to identify key opportunities for intervention throughout its chapters.

The main reasons behind fugitive emissions during the distribution of natural gas include the network's age, the material composition of the system, and the inefficiencies in leak detection and repair practices deployed by the different distribution companies. While regulators act precisely and efficiently on the first two factors, the latter present lack of strictness, allowing fugitive emissions to arise.

Policy intervention that can help mitigate such impacts revolves around reducing leak existence time, specifically, the time a leak is left open, and allowed to directly scatter methane into the atmosphere.

To achieve this, policymakers and companies have different options, each different depending on the existence phase of a leak subject to the reduction, dividing the leak timings in two main phases, pre-localization phase and post-localization phase, with the main difference being the knowledge relative to the existence and location of a leak.

Currently regulators do not account for the environmental impact of leaks, considering only their explosive threat and danger to society.

The company examined in the document, a leading distribution company in the Italian network, was found to emit the most during the pre-localization phase, when the leak's existence is unknown and needs to be detected for the first time, while post-localization emissions account for a small portion of the overall emissions.

The costs of leaks and emissions can be divided into two main factors: the economic value of the natural gas lost in the atmosphere and the environmental impact of the greenhouse potential of the methane emitted. The latter being three time greater than the former, highlighting the significant environmental costs of fugitive methane emissions.

Leak detection and repair costs are economically imbalanced, favoring the leak elimination side, both dominated by personnel costs related to the hours of work of the operators, but while leak elimination is composed by another 50% of structural costs that depend on the number of leaks that have to be repaired, network inspection result in lower overall costs since company's costs are only due to the amount of time dedicated to leak detection surveying.

Leak elimination is currently scheduled depending on the physical threat a leak poses to citizens, prioritizing leaks that have a higher risk of causing damages, without taking into account the environmental impact of the emissions.

The document developed models that incorporated the environmental aspect on the prioritization of leaks repair. Initially, it prioritized emissions reduction while keeping company costs constant, yielding positive environmental benefits without added costs. Subsequently, it included both environmental and physical danger considerations, keeping immediate-threat leaks constant. This

approach showed limited additional benefits, emphasizing that achieving both physical and environmental risk reduction requires increased efficiency or investment in personnel for repairs.
Leak detection on the other hand resulted to be more efficient, due to the high volume of emissions estimated to happen before the detection of a leak. Investments aimed at decreasing the time before a leak is found and quickening the detection, the emissions estimated decrease steeply with a positive return on investment, suggesting that policies regarding the increase in inspection frequency could translate in a more efficient allocation of resources.
Leak detection can be performed by third-party communication, since whoever smells or hears a leak can notify its presence to the local distribution company, reducing the overall time of repair, and by doing so citizens fulfill a key role in leak detection functioning as additional sensors. Enhancing citizen engagement through methods that facilitate reporting and increase awareness is crucial to improve abatement measures, enabling them to make the difference in emission reduction. However, Italian regulations discourage cooperation between companies and citizens by economically fine companies that do not decrease the number of thor-party notification and rewarding companies for reducing them, creating a counterproductive dynamic.
The document also examined the new regulatory landscape developed by the European Union through the entry into force of Regulation 1787 which targets and aims to reduce all methane emissions arising within the energy sector.
The analysis found that while enforcing stricter leak elimination deadlines, the impact on inspection frequency rate is modest, requiring only a 4% increase in annual survey coverage when compared to the current Italian normative setup. Citizen engagement remained unaddressed in the regulation leaving the relationship between companies and citizens still governed by the Italian standards.
On the other hand, the inclusion of monitoring, reporting and verification of distribution networks by the regulation covers an important gap, aiming to enhance data transparency and reliability, creating the foundations for future trustworthy dataset development.
After a detailed exam the results that arose from the analysis reveal that leak detection is the primary source for methane fugitive emissions abatement with the potential to ensure groundbreaking reduction with positive returns in terms of both economical and environmental benefits.
The complexity of the supply chain does not allow distribution companies to directly benefit from such detection investments, as the natural gas recovered is not of their possession, erasing positive investments. Policymakers must enable companies to take advantage of their good practices, incentivizing fugitive emissions abatement, and rewarding efficiency.
However, the normative landscape underestimates this potential, focussing instead on stricter leak elimination deadlines without leveraging the capabilities of citizen engagement, missing on key perspectives for fugitive methane emissions abatement.
Normative should incentivize citizen enhancement moving away from the current formula that penalizes companies receiving third-party notification, creating awareness campaigns and digital tools to facilitate public leak detection.
In addition to that, companies should be encouraged to invest and develop advanced technologies, such as aerial surveys and AI-driven predictive systems, subsidizing the adoption with incentives and tax reliefs.
Regulation 1787 must incorporate citizen participation harmonizing the detection framework, as well as increasing the strictness around leak detection, preventing all investments to be allocated on an efficient increase in leak elimination.
While the document provides a robust analysis, several areas remain in need of deeper examination and warrant further investigations.

Future studies should examine the results of Regulation 1787 with ex-post cost-benefit analysis of companies' environmental performances, and analyze new data derived from enhanced monitoring procedures reducing uncertainties in current emissions estimates.
Advanced technologies, such as arial detecting tools and AI-driven predictive systems should be explored alongside targeted subsidies and tax incentives to promote their adoption and increase efficiency. Citizen participation requires development and a coherent and dedicated framework to improve monitoring and reporting procedures, in alignment with the European Union's climate goals.
By integrating these elements, future research can build upon this work, contributing to a more sustainable and efficient natural gas distribution system.

Annex

Tables that have not been previously shown in the document will follow a romani enumeration (from table I to table LXII) while tables that have already been exhibited while the different chapters will follow an arabic enumeration (from table 1 to table 72).

Annex I - Database description

Annex I.I - Technical database description

The 80 variables are organized into six categories and listed in the order they appear in the dataset.

- Dati Infrastruttura
- Dispersioni RFP
- Dispersioni Terzi
- Dispersioni Danni
- Tempo Localizzazione
- Tempo Eliminazione

The database "dati infrastruttura" is a database composed by the following company datasets, each expressing a feature of the network:

- "1 Comuni serviti"
- "2-7 Remi GRF"
- "3-4 Clienti PdR"
- "5-6 Consistenza rete"
- "8 Rete ispezionata"

The dataset shows all variables that are linked to the physical structure or features of the Company's network,and it has been used to geographically scope the network as well as base to develop estimated regarding all calculations involving network length and composition.

Infrastructure					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Comuni serviti	The number of municipalities where the company manages the distributing infrastructures and distributes natural gas.	Integer	141	146	5
Clienti attivi	The number of active clients to which the company distributes natural gas	Integer	1.116.831	1.144.369	5
REMI	The number of connection points between the transport pipelines and the distribution pipelines	Integer	110	116	5
GRF/IRI	Final pressure reduction points that lower the pressure of the gas distributed to make it usable	Integer	2.921	3.050	5
di cui >1200 kw	Final pressure reduction points with a power higher than 1200 kw	Integer	2.574	2.697	5
PDR totali	The number of redelivery points codes signaling a natural gas supply.	Integer	1.223.056	1.354.728	5
AP/MP	Kilometers of pipelines where the gas is distributed in high to medium pressure where high pressure is equal to values higher than 5bar while the medium is in a range that goes from 5 bar to 0,04 bar	Integer	8.647,176	8.964,428	5
BP	Kilometers of pipelines where the gas is distributed in low pressure with a value not higher than 0,04 bar	Integer	5.304,945	5.609,222	5
Tot	Total length of the distribution pipeline system in kilometers	Integer	13.952,121	14.573,649	5
Rete ispezionata	Length of the inspected pipeline system in kilometers every year	Integer	6.980	8.845	5

Table I *- Infrastructure*

The database “dispersioni CSI” is a database composed by the company dataset “9 dispersioni ricerca programmata”, expressing the number of leaks that have been found by the Company during inspections of the network.

Company scheduled inspections leaks					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
RFP rete A1	Leaks found by the company during the scheduled inspections of class A1 coming from the distribution pipelines	Integer	14	31	5
RFP rete A2	Leaks found by the company during the scheduled inspections of class A2 coming from the distribution pipelines	Integer	59	152	5
RFP rete B	Leaks found by the company during the scheduled inspections of class B coming from the distribution pipelines	Integer	136	307	5
RFP rete C	Leaks found by the company during the scheduled inspections of class C coming from the distribution pipelines	Integer	92	296	5
RFP rete TOT	The total number of leaks found by the company during the scheduled inspections from the distribution pipelines	Integer	301	743	5
RFP allacci interrati A1	Leaks found by the company during the scheduled inspections of class A1 coming from the connections between pipelines settled under terrain surface	Integer	8	14	5
RFP allacci interrati A2	Leaks found by the company during the scheduled inspections of class A2 coming from the connections between pipelines settled under terrain surface	Integer	20	36	5

RFP allacci interrati B	Leaks found by the company during the scheduled inspections of class B coming from the connections between pipelines settled under terrain surface	Integer	31	89	5
RFP allacci interrati C	Leaks found by the company during the scheduled inspections of class C coming from the connections between pipelines settled under terrain surface	Integer	53	152	5
RFP allacci interrati TOT	The total number of leaks found by the company during the scheduled inspections coming from the connections between pipelines settled under terrain surface	Integer	112	269	5
RFP allacci aerei A1	Leaks found by the company during the scheduled inspections of class A1 coming from the connections between pipelines settled over terrain surface	Integer	123	573	5
RFP allacci aerei A2	Leaks found by the company during the scheduled inspections of class A2 coming from the connections between pipelines settled under terrain surface	Integer	0	5	5
RFP allacci aerei B	Leaks found by the company during the scheduled inspections of class B coming from the connections between pipelines settled under terrain surface	Integer	0	2	5
RFP allacci aerei C	Leaks found by the company during the scheduled inspections of class C coming from the connections between pipelines settled under terrain surface	Integer	213	1245	5

RFP allacci aerei TOT	The total number of leaks found by the company during the scheduled inspections coming from the connections between pipelines settled under terrain surface	Integer	421	1821	5
RFP GdM A1	Leaks found by the company during the scheduled inspections of class A1 coming from gas meters	Integer	56	385	5
RFP GdM A2	Leaks found by the company during the scheduled inspections of class A2 coming from gas meters	Integer	0	0	5
RFP GdM B	Leaks found by the company during the scheduled inspections of class B coming from gas meters	Integer	0	0	5
RFP GdM C	Leaks found by the company during the scheduled inspections of class C coming from gas meters	Integer	60	284	5
RFP GdM TOT	The total number of leaks found by the company during the scheduled inspections coming from gas meters	Integer	134	669	5

Table II *- Company scheduled inspection leaks*

The database "TPN leaks" is a database composed by the company dataset "10 dispersioni terzi", expressing the number of leaks that have been found after third party notifications.

Third-party notified leaks					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Terzi rete A1	Leaks found after third parties notification of class A1 coming from the distribution pipelines	Integer	110	185	5
Terzi rete A2	Leaks found after third parties notification of class A2 coming from the distribution pipelines	Integer	6	18	5
Terzi rete B	Leaks found after third parties notification of class B coming from the distribution pipelines	Integer	2	15	5
Terzi rete C	Leaks found after third parties notification of class C coming from the distribution pipelines	Integer	27	54	5
Terzi rete TOT	The total number of leaks found after third parties notification from the distribution pipelines	Integer	169	244	5
Terzi allacci interrati A1	Leaks found after third parties notification of class A1 coming from the connections between pipelines settled under terrain surface	Integer	104	171	5
Terzi allacci interrati A2	Leaks found after third parties notification of class A2 coming from the connections between pipelines settled under terrain surface	Integer	9	16	5
Terzi allacci interrati B	Leaks found after third parties notification of class B coming from the connections between pipelines settled under terrain surface	Integer	5	24	5

Terzi allacci interrati C	Leaks found after third parties notification of class C coming from the connections between pipelines settled under terrain surface	Integer	39	60	5
Terzi allacci interrati TOT	The total number of leaks found after third parties notification coming from the connections between pipelines settled under terrain surface	Integer	183	237	5
Terzi allacci aerei A1	Leaks found after third parties notification of class A1 coming from the connections between pipelines settled over terrain surface	Integer	772	1258	5
Terzi allacci aerei A2	Leaks found after third parties notification of class A2 coming from the connections between pipelines settled under terrain surface	Integer	3	19	5
Terzi allacci aerei B	Leaks found after third parties notification of class B coming from the connections between pipelines settled under terrain surface	Integer	3	16	5
Terzi allacci aerei C	Leaks found after third parties notification of class C coming from the connections between pipelines settled under terrain surface	Integer	2420	3384	5
Terzi allacci aerei TOT	The total number of leaks found after third parties notification coming from the connections between pipelines settled under terrain surface	Integer	3387	4520	5

Terzi GdM A1	Leaks found after third parties notification of class A1 coming from gas meters	Integer	524	1780	5
Terzi GdM A2	Leaks found after third parties notification of class A2 coming from gas meters	Integer	0	0	5
Terzi GdM B	Leaks found after third parties notification of class B coming from gas meters	Integer	0	0	5
Terzi GdM C	Leaks found after third parties notification of class C coming from gas meters	Integer	730	1777	5
Terzi GdM TOT	The total number of leaks found after third parties notification coming from gas meters	Integer	134	669	5

Table III *- Third-party notified leaks*

The database “damages leaks” is a database composed by the company dataset “10 bis dispersioni danni”, expressing the number of leaks that have been found after third party notifications and have been caused by third party damages to the network.

Damages leaks					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Danni rete A1	Leaks found after third parties damages of class A1 to the distribution pipelines	Integer	19	32	5
Danni rete A2	Leaks found after third parties damages of class A2 coming to distribution pipelines	Integer	0	3	5
Danni rete B	Leaks found after third parties damages of class B coming to distribution pipelines	Integer	0	1	5
Danni rete C	Leaks found after third parties damages of class C to distribution pipelines	Integer	0	5	5
Danni rete TOT	The total number of leaks found after third parties damages to distribution pipelines	Integer	22	38	5
Danni allacci interrati A1	Leaks found after third parties damages of class A1 coming to connections between pipelines settled under terrain surface	Integer	84	121	5
Danni allacci interrati A2	Leaks found after third parties damages of class A2 to connections between pipelines settled under terrain surface	Integer	1	5	5
Danni allacci interrati B	Leaks found after third parties damages of class B to connections between pipelines settled under terrain surface	Integer	1	4	5
Danni allacci interrati C	Leaks found after third parties damages of class C to connections between pipelines settled under terrain surface	Integer	3	17	5

Danni allacci interrati TOT	The total number of leaks found after third parties damages to connections between pipelines settled under terrain surface	Integer	89	134	5
Danni allacci aerei A1	Leaks found after third parties damages of class A1 to connections between pipelines settled over terrain surface	Integer	33	70	5
Danni allacci aerei A2	Leaks found after third parties damages of class A2 to connections between pipelines settled under terrain surface	Integer	0	1	5
Danni allacci aerei B	Leaks found after third parties damages of class B to connections between pipelines settled under terrain surface	Integer	0	1	5
Danni allacci aerei C	Leaks found after third parties damages of class C to connections between pipelines settled under terrain surface	Integer	23	38	5
Danni allacci aerei TOT	The total number of leaks found after third parties damages to connections between pipelines settled under terrain surface	Integer	59	94	5
Danni GdM A1	Leaks found after third parties damages of class A1 to gas meters	Integer	0	6	5
Danni GdM A2	Leaks found after third parties damages of class A2 to gas meters	Integer	0	0	5
Danni GdM B	Leaks found after third parties damages of class B to gas meters	Integer	0	0	5
Danni GdM C	Leaks found after third parties damages of class C to gas meters	Integer	1	4	5
Danni GdM TOT	The total number of leaks found after third parties damages to gas meters	Integer	1	8	5

Table IV - Damages leaks

The database “localization time” is a database composed by the company dataset “15 tempo localizzazione e eliminazione”, expressing the time that the Company spends to localize emissions, expressed in minutes, while for the estimations the values are then expressed in minutes.

Localization time (min)					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Rete	Average time spent to locate a leak coming from the pipelines	Real	15.044,00	20.716,00	5
Allacciamento interrato	Average time spent to locate a leak coming from connection between pipelines located under terrain surface	Real	10.152,00	19.713,00	5
Allacciamento aereo	Average time spent to locate a leak coming from connection between pipelines located over terrain surface	Real	127,00	598,40	5
Gruppo di Misura	Average time spent to locate a leak coming from gas meters	Real	14,00	25,00	5

Table V - Localization time

The database "elimination time" is a database composed by the company dataset "15 tempo localizzazione e eliminazione", expressing the time that the Company spends to eliminate emissions, expressed in minutes, while for the estimations the values are then expressed in minutes.

Elimination time (min)					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Rete A1	Average time spent to eliminate a leak of class A1 coming from distribution pipelines	Real	238,30	378,20	5
Rete A2	Average time spent to eliminate a leak of class A2 coming from distribution pipelines	Real	3013,00	4470,00	5
Rete B	Average time spent to eliminate a leak of class B coming from distribution pipelines	Real	20369,00	26211,00	5
Rete C	Average time spent to eliminate a leak of class C coming from distribution pipelines	Real	39018,00	68282,00	5
Allacci interrati A1	Average time spent to eliminate a leak of class A1 coming from connections between pipelines located under terrain surface	Real	157,00	415,00	5
Allacci interrati A2	Average time spent to eliminate a leak of class A2 coming from connections between pipelines located under terrain surface	Real	2412,00	6230,00	5
Allacci interrati B	Average time spent to eliminate a leak of class B coming from connections between pipelines located under terrain surface	Real	17695,00	22804,00	5
Allacci interrati C	Average time spent to eliminate a leak of class C coming from connections between pipelines located under terrain surface	Real	48451,00	73229,00	5

Allacci aerei A1	Average time spent to eliminate nare a leak of class A1 coming from connections between pipelines located above terrain surface	Real	20,95	36,90	5
Allacci aerei A2	Average time spent to eliminate a leak of class A2 coming from connections between pipelines located above terrain surface	Real	0,00	6990,00	5
Allacci aerei B	Average time spent to eliminate a leak of class coming from connections between pipelines located above terrain surface	Real	0,00	15670,00	5
Allacci aerei C	Average time spent to eliminate a leak of class C coming from connections between pipelines located above terrain surface	Real	6340,00	40890,00	5
GdM A1	Average time spent to eliminate a leak of class A1 coming from gas meters	Real	13,82	24,87	5
GdM A2	Average time spent to eliminate a leak of class A2 coming from gas meters	Real	0,00	0,00	5
GdM B	Average time spent to eliminate a leak of class B coming from gas meters	Real	0,00	0,00	5
GdM C	Average time spent to eliminate a leak of class C coming from gas meters	Real	22,95	5111,22	5

Table VI *- Elimination time*

Summary statistics

Network						
Summary	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Comuni serviti	141	143	145	144	146	146
Clienti attivi	11.116.831	1.117.476	1.127.982	1.129.625	1.141.955	1.144.369
REMI	110	112	114	114	116	116
GRF/IRI	2.921	2.930	2.984	2.986	3.046	3.050
di cui >1200 Kw	2.574	2.578	2.610	2.618	2.654	2.679
PdR totali	1.223.056	1.225.486	1.242.763	1.258.012	1.259.468	1.354.728
AP/MP (Km)	8.647.176	8.664.475	8.815.645	8.811.293	8.961.994	8.964.428
BP (Km)	5.304.945	5.309.118	5.456.002	5.456.765	5.604.697	5.609.222
TOT (Km)	1.395.121	13.973.619	14.271.621	14.268.058	14.566.691	14.573.649
Rete ispezionata (Km)	6.980	7.602	7.752	7.878	8.228	8.845

Table VII - *Summary statistics "Network"*

Company scheduled inspections leaks						
Summary	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Rete A1	14,00	16,00	22,00	22,00	28,00	31,00
Rete A2	59,00	70,00	93,00	96,00	110,00	152,00
Rete B	136,00	181,00	244,00	234,00	295,00	307,00
Rete C	92,00	222,00	245,00	228,00	269,00	296,00
TOT Rete	301,00	538,00	637,00	580,00	652,00	743,00
Allacci Interrati A1	8,00	9,00	10,00	11,00	12,00	14,00
Allacci Interrati A2	20,00	24,00	28,00	29,00	34,00	36,00
Allacci Interrati B	31,00	51,00	63,00	62,00	75,00	89,00
Allacci Interrati C	31,00	51,00	63,00	62,00	75,00	89,00
TOT Allacci Interrati	112,00	198,00	234,00	217,00	260,00	269,00
Allacci Aerei A1	0,00	1,00	1,00	1,00	1,00	2,00
Allacci Aerei A2	56,00	78,00	108,00	145,00	134,00	385,00
Allacci Aerei B	0,00	1,00	2,00	2,00	2,00	5,00
Allacci Aerei C	213,00	316,00	426,00	558,00	677,00	1245,00
TOT Allacci Aerei	421,00	580,00	613,00	853,00	964,00	1821,00
GdM A1	134,00	164,00	212,00	282,00	293,00	669,00
GdM A2	56,00	78,00	108,00	145,00	134,00	385,00
GdM B	0,00	0,00	0,00	0,00	0,00	0,00
GdM C	0,00	0,00	0,00	0,00	0,00	0,00
TOT GdM	60,00	78,00	126,00	138,00	159,00	284,00

Table VIII *- Summary statistics "Company inspection leaks"*

Third-party notified leaks						
Summary	**Min**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max**
Rete A1	110	127	151	148	166	185
Rete A2	6,00	10,00	14,00	13,00	18,00	18,00
Rete B	2,00	7,00	11,00	10,00	14,00	15,00
Rete C	27,00	34,00	37,00	38,00	39,00	54,00
TOT Rete	169,00	182,00	208,00	208,00	238,00	244,00
Allacci Interrati A1	104,00	141,00	148,00	143,00	150,00	171,00
Allacci Interrati A2	9,00	10,00	13,00	13,00	15,00	16,00
Allacci Interrati B	5,00	13,00	17,00	16,00	19,00	24,00
Allacci Interrati C	39,00	41,00	43,00	45,00	45,00	60,00
TOT Allacci Interrati	183,00	210,00	219,00	217,00	231,00	237,00
Allacci Aerei A1	772,00	951,00	1.040,00	1.041,00	1.170,00	1.258,00
Allacci Aerei A2	3,00	6,00	12,00	11,00	15,00	19,00
Allacci Aerei B	3,00	4,00	7,00	7,00	9,00	16,00
Allacci Aerei C	2.420,00	2.560,00	2.821,00	2.872,00	3.188,00	3.384,00
TOT Allacci Aerei	3.387,00	3.504,00	3.940,00	3.930,00	4.312,00	4.520,00
GdM A1	524,00	687,00	848,00	1.061,00	1.513,00	1.780,00
GdM A2	0,00	0,00	0,00	0,00	0,00	0,00
GdM B	0,00	0,00	0,00	0,00	0,00	0,00
GdM C	730,00	993,00	1.103,00	1.119,00	1.385,00	1.777,00
TOT GdM	1.254,00	1.687,00	1.943,00	2.252,00	2.898,00	3.557,00

Table IX *- Summary statistics "Third-party notified leaks"*

Damages leaks						
Summary	**Min**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max**
Rete A1	19	22	26	25,83	30	32
Rete A2	0	0,25	1	1	1	3
Rete B	0	0	0,5	0,5	1	1
Rete C	0	1,25	2,5	2,33	3	5
TOT Rete	22	27	29,5	29,67	32	38
Allacci Interrati A1	84	91,5	105	103	113,2	121
Allacci Interrati A2	1	2	2,5	2,67	3	5
Allacci Interrati B	1	1	1,5	2,17	3,5	4
Allacci Interrati C	3	5	11	10,17	14,75	17
TOT Allacci Interrati	89	106	126	118	131,8	134
Allacci Aerei A1	33	40	46	48	53	70
Allacci Aerei A2	0	0	1	1	1	1
Allacci Aerei B	0	0	0	0	0	0
Allacci Aerei C	23	24	25	27	28	38
TOT Allacci Aerei	59	65	73	76	88	94
GdM A1	0	2	2	3	3	6
GdM A2	0	0	0	0	0	0
GdM B	0	0	0	0	0	0
GdM C	1	1,25	2	2	2	4
TOT GdM	1	3,25	4,5	4,5	5,75	8

Table X *- Summary statistics "Damages leaks"*

Localization time (min)						
Leaks	**Min**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max**
Allacciamento Aereo	127,00	172,40	237,10	277,00	293,10	598,40
Gruppo di Misura	56,30	80,59	92,26	94,72	106,61	139,41
Allacciamento Interrato	10.152,00	15.989,00	16.609,00	16.084,00	17.380,00	19.713,00
Rete	15.044,00	17.163,00	18.316,00	18.269,00	19.911,00	20.716,00

Table XI *- Summary statistics "Localization time"*

Elimination time (min)						
Leaks	**Min**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max**
Rete A1	238,30	249,90	271,40	295,20	344,60	378,20
Rete A2	3013,00	3451,00	3819,00	3732,00	3911,00	4471,00
Rete B	20396,00	21346,00	22496,00	22819,00	23887,00	26211,00
Rete C	39018,00	48575,00	53883,00	54875,00	64002,00	68282,00
Allacci Interrati A1	157,00	214,40	302,20	296,10	386,50	415,50
Allacci Interrati A2	2412,00	3385,00	3884,00	4157,00	4957,00	6230,00
Allacci Interrati B	17695,00	19189,00	20979,00	20402,00	21266,00	22804,00
Allacci Interrati C	48451,00	50897,00	53959,00	57454,00	62429,00	73229,00
Allacci Aerei A1	20,95	24,94	27,40	28,33	31,76	36,90
Allacci Aerei A2	0,00	30,00	131,20	1345,40	650,70	6990,00
Allacci Aerei B	0,00	33,75	589,50	5048,83	10344,00	15670,00
Allacci Aerei C	6340,00	7259,00	9380,00	14321,00	12382,00	40890,00
GdM A1	13,82	21,23	22,05	21,26	23,39	24,87
GdM A2	0,00	0,00	0,00	0,00	0,00	0,00
GdM B	0,00	0,00	0,00	0,00	0,00	0,00
GdM C	22,95	231,28	275,39	1257,11	1299,71	5111,22

Table XII *- Summary statistics "Elimination time"*

Data Integrity

Completeness:
The data is overly aggregated, leaving very few observations that correspond only to the selected years (2017–2022). This prevents the creation of a dataset robust enough for a reliable estimation of emissions.

Consistency:
The consistency of the data from 2018 to 2022 appears to be excellent, with no significant trends or spikes observed. However, an increase in network length and the number of kilometers inspected could logically lead to a corresponding increase in detected leaks. It's possible that long-term inspections create a monitoring effect that keeps the number of leaks relatively stable.
The situation is different for the 2017 data, which exhibits a markedly different trend compared to other years, with instances accounting for more than 50% of the total accumulated leaks during the analysis period.

Accuracy:
Data related to infrastructure and inspection performance is accurate and reliable, as it results from company-led planning and is verified by the regulatory authority.
However, the accuracy and reliability of data concerning the number of detected leaks and their duration might be less robust due to the aggregation of the provided data. While the number of leaks is based on the sum of technicians' reports, the average values for durations oversimplify the data, rendering it almost useless for deeper analysis.
The dataset includes technical characteristics of the infrastructure, inspection performance for each analyzed year, the total number of detected leaks by priority class and source, the average time to locate leaks, and the average time to fix leaks for each priority class and source.
The dataset lacks disaggregated observations, referred to internally as Work Orders (ODL)

Annex I.II - Costs database description

The two datasets' are separated and describe the costs of inspection and elimination of fugitive emissions:

- Leak elimination costs
- Personnel_inspection_costs

The database "leak elimination costs" is a database composed by the company dataset "Pronto intervento", expressing the costs sustained by the Company eliminating leaks, divided by the different invoices that characterize the leak elimination procedures

Leak elimination costs					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Mezzi	Cost for the use of the company fleet	Integer	€ 162.504,00	€ 291.291,00	5
Materiali	Cost for the use of materials used during reparations and eliminations of fugitive emissions	Integer	€ 248.125,00	€ 401.188,00	5
Servizi	Cost of services related to the elimination of fugitive emissions	Integer	€ 1.365.363,00	€ 2.383.920,00	5
Oneri di gestione	Costs related to the management of the network	Integer	-€ 115.572,00	€ 17.628,00	5
Personale	Cost for the personnel involved in the elimination of fugitive emissions	Integer	€ 2.722.831,00	€ 4.178.030,00	5
Godimento di beni terzi	Cost for the use of others' services	Integer	€ 0,00	€ 60,00	5
Totale	Total cost of elimination of fugitive emissions for every year	Integer	€ 4.787.313,00	€ 7.160.258,00	5

Table XIII *- Leak elimination costs*

The database "scheduled inspection costs" is a database composed by the company dataset "RFP", expressing the personnel costs sustained by the Company for the scheduled inspections.

Leak elimination costs					
Variable name	**Description**	**Type**	**Min value**	**Max value**	**Observations**
Personale	Cost associated with the personal performing inspections on the network	Integer	€329.504,00	€445.655,00	5
Ore lavorate	Total time spent working on a year long span	Integer	€8.863,00	€11.537,00	5
Costo orario	Cost of every hour worked by any person on the operations staff	Integer	€37,18	€38,67	5
Full time equivalent	Costs related to the management of the network	Integer	€5,33	€6,93	5

Table XIV *- Scheduled inspection costs*

Summary statistics

Leak elimination costs						
Statistica	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
MEZZI	€ 162.504,00	€ 174.865,00	€ 215.244,00	€ 207.298,00	€ 233.189,00	€ 250.688,00
MATERIALI	€ 248.125,00	€ 258.159,00	€ 287.497,00	€ 318.772,00	€ 398.894,00	€ 401.188,00
SERVIZI	€ 1.365.363,00	€ 1.526.687,00	€ 1.659.176,00	€ 1.679.810,00	€ 1.772.331,00	€ 2.075.495,00
ALTRI ONERI DI GESTIONE	-€ 115.572,00	-€ 17.683,00	€ 2.486,00	-€ 23.024,00	€ 3.376,00	€ 12.275,00
PERSONALE	€ 2.722.831,00	€ 3.117.857,00	€ 3.216.956,00	€ 3.228.187,00	€ 3.417.749,00	€ 3.665.542,00
TOTALE	€ 4.787.313,00	€ 5.056.893,00	€ 5.598.798,00	€ 5.411.044,00	€ 5.679.618,00	€ 5.932.597,00

Table XV *- Summary statistics "Leak elimination costs"*

Personnel inspection costs						
Summary	**Min.**	**1st Qu.**	**Median**	**Mean**	**3rd Qu.**	**Max.**
Personale	€ 329.504,00	€ 380.097,00	€ 403.296,00	€ 397.989,00	€ 426.190,00	€ 445.655,00
Ore lavorate	8.863,00	10.029,00	10.634,00	10.503,00	11.302,00	11.537,00
Costo orario	€ 37,18	€ 37,36	€ 37,75	€ 37,87	€ 38,44	€ 38,67
Full time equivalent	5,33	6,03	6,39	6,31	6,79	6,93

Table XVI *- Summary statistics "Personnel inspection costs"*

Data Integrity

Completeness:
The data is overly aggregated, leaving very few observations that correspond only to the selected years (2017–2022). This prevents the creation of a dataset robust enough for a reliable estimation of emissions.

Consistency:
The consistency of the data from 2018 to 2022 appears to be excellent, with no significant trends or spikes observed.
The datasets appear consistent, especially the personnel inspection costs, as the range between min. and max values across the categories is reasonable and does not show or indicate possible outliers, and the FTE values are logically aligned with worked hours, showing no major discrepancies.
For the elimination leak costs, most categories exhibit stable trends between the 1st quartile, median and 3rd quartile, the "altri oneri di gestione" category shows inconsistency, including negative values which may indicate refunds, write offs or miss classifications.
Despite the anomalies the total remains structured with the mean positioned well near the median, suggesting no irregularity over the years analyzed.

Accuracy:
For inspection costs the data appears accurate and aligns with the expectations that might arise for personnel costs as well as for operational inputs, and the inclusion of worked hours, FTE and hourly costs supports validation and reliability, while the lack of breakdown by job roles or work typed limits further accuracy, as the aggregation do not give specific variances.
The data that characterize the elimination costs are generally accurate with some categories dominating the expenditures, reflecting the trends expected for emergency operations.The absence of disaggregated and detailed costs analysis limits the accuracy of deeper cost analysis, due to the major difficulty of underground leak elimination elimination that might create uncertainty of data since the operation that arise from it are uncertain and not perfectly managed.

Annex II - Company level case study data and results

The annex exhibits the yearly data that have been utilized to estimate the emissions arising from Company network for each of the examined years.
Annex II is divided following chapter 3 sequence of analysis.

Annex II.I - Generic emission estimation

Table XVII shows the network length divided into the different materials of which the network is composed, and every material is then divided in the part of network composed of that material that is operated either in High or medium pressure (HP/MP), that are aggregated due to the minimal share of high pressure operated network, and in low pressure (LP).
The data related to the network has been gathered from the Company dataset "Dati tecnici Company; 5-6 consistenza di rete".

	Steel network (Km)		Polyethylene network (Km)		Cast iron network (Km)		Total network (Km)		
Year	HP/MP	LP	HP/MP	LP	HP/MP	LP	HP/MP	LP	Total
2022	8.117,62	4.336,73	845,26	444,04	0,00	715,23	8.962,89	5.496,00	14.458,89
2021	8.120,33	4.332,61	844,09	412,49	0,00	721,84	8.964,43	5.466,94	14.431,37
2020	8.115,51	4.329,32	843,80	390,18	0,00	729,36	8.959,31	5.448,85	14.408,16
2019	7.854,82	4.040,68	817,16	369,32	0,00	738,28	8.671,98	5.148,29	13.820,27
2018	7.847,25	4.039,11	814,72	361,78	0,00	745,74	8.661,97	5.146,62	13.808,60

Notes: The network length is divided respectively in different materials and then in different operating pressure with the last three columns exhibiting the total values for the Company's network.

Table XVII - *Network length*

Table 10 shows the emissions factors that have been used to estimate the generic emissions coming out of the network depending on the length and on the material of the network. Data coming from the table "Leakage emission factor of natural gas for transmissions and distribution in pipelines by material and pressure" out of the *National Inventory Report* (NIR) issued by the Istituto superiore per la protezione e la ricerca ambientale (ISPRA).

Emission factor ISPRA 2023 (scm/km)					
Steel		Polyethylene		Cast iron	
MP	LP	MP	LP	MP	LP
319,90	207,50	189,90	189,90	391,00	328,30

Notes: The emissions factor are estimated by Ispra and are expressed in standard cubic meters of natural gas emitted every km of network, "Leakage emission factors of natural gas for transmission and distribution in pipelines by material and pressure (2022)".*National Inventory Report*,(2024)

Table 10. *Emission factors for different network materials*

Table 12 shows the results for the natural gas emission estimation, expressed in standard cubic meters of natural gas, that arise from the network, dividing it by material and operating pressure.

Result estimated by crossing the data related to the network length and the emissions factors estimated by ISPRA in the NIR.

Natural gas emission estimation (scm)	Steel		Polyethylene		Cast iron		
Year	MP	LP	MP	LP	MP	LP	TOT
2018	2.510.335,28	838.115,33	154.715,33	68.702,02	0,00	244.826,44	3.816.694,39
2019	2.512.756,92	838.441,10	155.178,68	70.133,87	0,00	242.377,32	3.818.887,89
2020	2.596.151,65	898.333,90	160.237,62	74.095,18	0,00	239.448,89	3.968.267,24
2021	2.597.693,57	899.016,58	160.292,69	78.331,85	0,00	236.980,07	3.972.314,76
2022	2.596.826,64	899.871,48	160.514,87	84.323,20	0,00	234.810,01	3.976.346,19
2018-2022	12.813.764,05	4.373.778,38	790.939,20	375.586,12	0,00	1.198.442,74	19.552.510,47

Notes: Results given by equation (1) crossing the data related to the network length and the EF estimated by ISPRA, divided in different materials.

Table 12. *Estimate emissions of natural gas from generic emission factor*

Table 13 shows the results for the natural gas emission estimation, expressed in cubic meters of methane, that arise from the network, dividing it by material and operating pressure.

Result estimated by crossing the data related to the network length and the emissions factors estimated by ISPRA in the NIR.

Methane emission estimation (m^3)	Steel		Polyethylene		Cast iron		
Year	HP/MP	LP	HP/MP	LP	HP/MP	LP	TOT
2018	2.309.508,45	771.066,10	142.338,10	63.205,86	0,00	225.240,33	3.511.358,84
2019	2.311.736,36	771.365,81	142.764,39	64.523,16	0,00	222.987,14	3.513.376,86
2020	2.388.459,52	826.467,19	147.418,61	68.167,57	0,00	220.292,98	3.650.805,86
2021	2.389.878,08	827.095,25	147.469,28	72.065,30	0,00	218.021,67	3.654.529,58
2022	2.389.080,51	827.881,76	147.673,68	77.577,34	0,00	216.025,21	3.658.238,50
2018-2022	11.788.662,92	4.023.876,11	727.664,06	345.539,23	0,00	1.102.567,32	17.988.309,64

Notes: Estimated methane emissions divided in materials and operating pressure for every year estimated by crossing the Company network length and the emission factor for every material and operating pressure and the generic emissions factors (ISPRA)

Table 13. *Estimate emissions of methane from generic emission factor*

Annex II.II - Current time overview

Tab XVIII through XX show the number of leaks divided by priority class and pre-localization method for every year taken into consideration for the document.
All data has been gathered from the Company in the dataset "Dati tecnici Company; 9 dispersioni da ricerca programmata, 10 dispersioni terzi, 10bis dispersioni danni."
Every table represents a different emitting source and the number of leaks represents the number of leaks of such sources that have been located and eliminated by the Company.

Source	**Aboveground**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	1.192	123	13	1	7	1	2.555	296
2019	991	374	15	2	4	1	2.449	213
2020	805	152	12	5	16	2	2.673	477
2021	1.308	326	5	2	6	0	3.275	744
2022	1.011	202	4	0	3	0	3.422	374

Table XVIII - *Number of aboveground leaks*

Source	**Gas meter**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	1.686	140	0	0	0	0	1.468	168
2019	1.000	116	0	0	0	0	1.150	130
2020	685	56	0	0	0	0	1.058	121
2021	697	71	0	0	0	0	973	63
2022	527	100	0	0	0	0	732	60

Table XIX - *Number of gas meter leaks*

Source	Underground components							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	237	13	13	25	14	49	51	103
2019	225	14	14	36	28	77	50	142
2020	253	10	17	35	20	68	74	152
2021	261	9	19	24	19	57	56	133
2022	270	10	13	31	19	89	56	114

Table XX *- Number of underground components leaks*

Source	Underground Pipelines							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	173	19	19	97	2	170	59	219
2019	144	31	12	152	13	302	37	258
2020	141	15	17	114	9	213	34	296
2021	197	24	19	64	16	275	42	272
2022	182	29	9	89	6	307	30	231

Table XXI - *Number of underground pipelines leaks*

Table XXII through XXV show the latency time divided by priority class and pre-localization method for every year taken into consideration for the document.
All data has been estimated from Company data present in the dataset "Dati tecnici Company; 5-6 consistenza rete8 rete ispezionata".
Every table represents a different emitting source and the time shown represents the latency time for every leak of that specific category.

Source	**Aboveground**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	1,00	1,00	1,00	16.025,74	1,00	16.025,74	1,00	16.025,74
2019	1,00	1,00	1,00	16.135,08	1,00	16.135,08	1,00	16.135,08
2020	1,00	1,00	1,00	16.216,47	1,00	16.216,47	1,00	16.216,47
2021	1,00	1,00	1,00	15.293,11	1,00	15.293,11	1,00	15.293,11
2022	1,00	1,00	1,00	14.427,98	1,00	14.427,98	1,00	14.427,98

Notes: Expressed in hours

Table XXII *- Aboveground leaks latency time*

Source	**Gas meter**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	1,00	1,00	0,00	0,00	0,00	0,00	1,00	16.025,74
2019	1,00	1,00	0,00	0,00	0,00	0,00	1,00	16.135,08
2020	1,00	1,00	0,00	0,00	0,00	0,00	1,00	16.216,47
2021	1,00	1,00	0,00	0,00	0,00	0,00	1,00	15.293,11
2022	1,00	1,00	0,00	0,00	0,00	0,00	1,00	14.427,98

Notes: Expressed in hours

Table XXIII - *Gas meter leaks latency time*

Source	**Underground components**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	1,00	16.025,74	16.025,74	16.025,74	16.025,74	16.025,74	16.025,74	16.025,74
2019	1,00	16.135,08	16.135,08	16.135,08	16.135,08	16.135,08	16.135,08	16.135,08
2020	1,00	16.216,47	16.216,47	16.216,47	16.216,47	16.216,47	16.216,47	16.216,47
2021	1,00	15.293,11	15.293,11	15.293,11	15.293,11	15.293,11	15.293,11	15.293,11
2022	1,00	14.427,98	14.427,98	14.427,98	14.427,98	14.427,98	14.427,98	14.427,98

Notes: Expressed in hours

Table XXIV -*Underground components leaks latency time*

Source	**Underground Pipelines**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	1,00	16.025,74	16.025,74	16.025,74	16.025,74	16.025,74	16.025,74	16.025,74
2019	1,00	16.135,08	16.135,08	16.135,08	16.135,08	16.135,08	16.135,08	16.135,08
2020	1,00	16.216,47	16.216,47	16.216,47	16.216,47	16.216,47	16.216,47	16.216,47
2021	1,00	15.293,11	15.293,11	15.293,11	15.293,11	15.293,11	15.293,11	15.293,11
2022	1,00	14.427,98	14.427,98	14.427,98	14.427,98	14.427,98	14.427,98	14.427,98

Notes: Expressed in hours

Table XXV - *Underground pipelines leaks latency time*

Table XXVI shows the localization time divided by source for every year taken into consideration by the document.
All data has been estimated from Company data present in the dataset “Dati tecnici Company; 15 tempo localizzazione eliminazione”.

Year	Aboveground	Gas meter	Underground components	Underground pipelines
2018	5,2	1,4	169,2	250,7
2019	2,5	2,3	293,3	338,0
2020	10,0	1,8	328,6	345,3
2021	3,9	1,6	278,7	297,1
2022	4,0	0,9	263,7	313,5

Notes: Expressed in hours

Table XXVI - *Localization times*

Tables XXVII through XXX shows the scheduling times divided by priority class for every year taken into consideration by the document.
All data has been estimated from Company data present in the dataset “Dati tecnici Company; 15 tempo localizzazione eliminazione”.
Every table represents a different emitting source and the time shown represents the scheduling time for every leak of that specific category.

Source	**Aboveground**			
Priority class	A1	A2	B	C
2018	1,00	116,07	260,74	130,56
2019	1,00	0,11	0,18	117,29
2020	1,00	12,8	223,12	181,25
2021	1,00	0,01	0,03	213,97
2022	1,00	25,62	96,64	105,13

Notes: Expressed in hours

Table XXVII - *Aboveground leaks scheduling time*

Source	**Gas meter**			
Priority class	A1	A2	B	C
2018	1,00	0,00	0,00	26,77
2019	1,00	0,00	0,00	3,56
2020	1,00	0,00	0,00	3,46
2021	1,00	0,00	0,00	4,88
2022	1,00	0,00	0,00	0,38

Notes: Expressed in hours

Table XXVIII - *Gas meters leaks scheduling time*

Source	Underground components			
Priority class	A1	A2	B	C
2018	1,00	52,57	303,45	942,63
2019	1,00	81,46	289,56	1065,43
2020	1,00	101,21	352,9	804,89
2021	1,00	66,8	347,96	845,9
2022	1,00	50,68	375,36	1215,78

Notes: Expressed in hours

Table XXIX - *Underground components leaks scheduling time*

Source	Underground pipelines			
Priority class	A1	A2	B	C
2018	1,00	58,25	346,47	969,74
2019	1,00	69,78	379,69	1092,27
2020	1,00	59,01	398,71	816,32
2021	1,00	61,15	361,13	801,7
2022	1,00	46,11	432,74	1133,93

Notes: Expressed in hours

Table XXX - *Underground pipelines leaks scheduling time*

Tab XXXI shows the repair time divided by source for every year taken into consideration by the document.
All data has been estimated from Company data present in the dataset "Dati tecnici Company; 15 tempo localizzazione eliminazione".

Year	Aboveground	Gas meter	Underground components	Underground pipelines
2018	0,43	0,36	6,92	6,08
2019	0,35	0,35	5,36	4,73
2020	0,41	0,38	2,62	3,97
2021	0,62	0,39	3,19	4,32
2022	0,54	0,41	4,71	4,11

Notes: Expressed in hours

Table XXXI - *Repair time*

Annex II.III - Source emission estimation

Table XXXII shows the factors responsible for the estimation of the underground emission factors, that are estimated by reverse engineering the generic emission estimation derided using the emission factors that ISPRA estimated in the National Inventory Report of 2024.
The generic emission estimation has been divided by the total underground activity factor resulting from the sum of the total emitting time for all leaks, which expresses the total time a leak is kept open emitting and is the result of all the emitting phases of every leak.
The results express the average amount of natural gas an underground leak is expected to leak during a unit of time, that for the document is one hour.

Generic emission estimation (scm)	Underground activity factor (h)	Underground emission factor (scm/h)
3.816.694,39	14.456.641,17	0,26
3.818.887,89	20.006.847,60	0,19
3.968.267,24	18.502.480,21	0,21
3.972.314,76	16.725.578,70	0,24
3.976.346,19	16.032.408,25	0,25

Notes: The table exhibits the generic emission estimation resulted from the first emission estimation estimated by using the emission factor related to the materiality of the network, the underground activity factor represents the sum of the total pre and post localization time of the leaks expressing the total time underground leaks are kept open and is expressed in hours, the underground emissions factor expresses the amount of natural gas emitted every hour by underground leaks.

Table XXXII *- Underground emission factors*

Table 18 shows the different emissions factors, expressed in standard cubic meters of natural gas per hour, that have been used in the document for estimation purposes.

Source	Leak number	Emission factors (scm/h)
Aboveground	23.061	0,01
Underground	7.238	0,23
Gas meters	11.001	0,005

Notes: The Emissions factor is expressed as standard cubic meter of neutral gas leaking out of the leaks by the different sources.
Data derived from
Methane emission estimation method for the gas distribution grid, European gas research group (2018)
National inventory report, Istituto superiore per la protezione e la ricerca ambientale (2024)

Table 18 *Emission factors*

Annex II.III.I - Pre-localization emission estimation

Table XXXIII through XXXVI show the disaggregated latency phase estimated emissions results for aboveground leaks, gas meter leaks , underground components leaks and underground pipelines leaks, resulting from the multiplication of the number of leaks by the incubation time of the leaks.
The values are exhibited divided by priority class, pre-localization method and the year of their elimination.

Source	**Aboveground**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	11,92	1,23	0,13	160,26	0,07	160,26	25,55	47.436,20
2019	9,91	3,74	0,15	322,70	0,04	161,35	24,49	34.367,73
2020	8,05	1,52	0,12	810,82	0,16	324,33	26,73	77.352,56
2021	13,08	3,26	0,05	305,86	0,06	0,00	32,75	113.780,73
2022	10,11	2,02	0,04	0,00	0,03	0,00	34,22	53.960,64

Notes: Expressed in standard cubic meter of natural gas

Table XXXIII *- Aboveground leaks latency phase estimated emissions*

Source	**Gas meter**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	8,43	0,70	0,00	0,00	0,00	0,00	7,34	13.461,62
2019	5,00	0,58	0,00	0,00	0,00	0,00	5,75	10.487,80
2020	3,43	0,28	0,00	0,00	0,00	0,00	5,29	9.810,96
2021	3,49	0,36	0,00	0,00	0,00	0,00	4,87	4.817,33
2022	2,64	0,50	0,00	0,00	0,00	0,00	3,66	4.328,39

Notes: Expressed in standard cubic meter of natural gas

Table XXXIV - *Gas meter latency phase leaks estimated emissions*

Source	Underground components							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	54,51	47.916,97	47.916,97	92.148,02	51.602,89	180.610,12	187.981,96	379.649,84
2019	51,75	51.954,96	51.954,96	133.598,48	103.909,93	285.752,31	185.553,45	526.971,78
2020	58,19	37.297,88	63.406,40	130.542,58	74.595,76	253.625,58	276.004,31	566.927,77
2021	60,03	31.656,73	66.830,88	84.417,96	66.830,88	200.492,65	196.975,24	467.816,19
2022	62,10	33.184,35	43.139,65	102.871,48	63.050,26	295.340,71	185.832,35	378.301,58

Notes: Expressed in standard cubic meter of natural gas

Table XXXV - *Underground components latency phase leaks estimated emissions*

Source	Underground Pipelines							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	39,79	70.032,50	70.032,50	357.534,32	7.371,84	626.606,54	217.469,33	807.216,66
2019	33,12	115.043,14	44.532,83	564.082,47	48.243,90	1.120.742,81	137.309,55	957.455,78
2020	32,43	55.946,82	63.406,40	425.195,83	33.568,09	794.444,83	126.812,79	1.104.017,23
2021	45,31	84.417,96	66.830,88	225.114,56	56.278,64	967.289,11	147.731,43	956.736,86
2022	41,86	96.234,61	29.865,91	295.340,71	19.910,61	1.018.759,52	99.553,05	766.558,46

Notes: Expressed in standard cubic meter of natural gas

Table XXXVI - *Underground pipelines latency phase leaks estimated emissions*

Table XXXVII through XL show the disaggregated localization time estimated emissions results for aboveground leaks, gas meter leaks , underground components leaks and underground pipelines leaks, resulting from the multiplication of the number of leaks by the localization time of the leaks.
The values are then multiplied by the factor related to the percentage of methane present in the Italian natural gas mix which as stated by ISPRA and Snam is equal to 92%.
The values are exhibited divided by priority class, pre-localization method and the year of their elimination.

Source	**Aboveground**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	61,89	6,39	0,67	0,05	0,36	0,05	132,65	15,37
2019	24,96	9,42	0,38	0,05	0,10	0,03	61,68	5,36
2020	80,28	15,16	1,20	0,50	1,60	0,20	266,58	47,57
2021	51,51	12,84	0,20	0,08	0,24	0,00	128,97	29,30
2022	40,10	8,01	0,16	0,00	0,12	0,00	135,74	14,84

Notes: Expressed in standard cubic meter of natural gas

Table XXXVII - *Aboveground localization phase leaks estimated emissions*

Source	**Gas meter**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	12,21	1,01	0,00	0,00	0,00	0,00	10,63	1,22
2019	11,62	1,35	0,00	0,00	0,00	0,00	13,36	1,51
2020	6,26	0,51	0,00	0,00	0,00	0,00	9,66	1,11
2021	5,67	0,58	0,00	0,00	0,00	0,00	7,91	0,51
2022	2,47	0,47	0,00	0,00	0,00	0,00	3,43	0,28

Notes: Expressed in standard cubic meter of natural gas

Table XXXVIII - *Gas meters localization phase leaks estimated emissions*

Source	Underground components							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	9.223,36	505,92	505,92	972,93	544,84	1.906,94	1.984,77	4.008,46
2019	15.178,34	944,43	944,43	2.428,53	1.888,86	5.194,37	3.372,96	9.579,22
2020	19.118,69	755,68	1.284,66	2.644,88	1.511,36	5.138,62	5.592,03	11.486,33
2021	16.733,03	577,00	1.218,11	1.538,67	1.218,11	3.654,34	3.590,23	8.526,79
2022	16.375,46	606,50	788,45	1.880,15	1.152,35	5.397,84	3.396,39	6.914,08

Notes: Expressed in standard cubic meter of natural gas

Table XXXIX - *Underground components localization phase leaks estimated emissions*

Source	Underground Pipelines							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	9.976,97	1.095,74	1.095,74	5.594,02	115,34	9.803,96	3.402,55	12.629,80
2019	11.194,11	2.409,84	932,84	11.816,01	1.010,58	23.476,54	2.876,27	20.056,12
2020	11.197,26	1.191,20	1.350,02	9.053,11	714,72	16.915,02	2.700,05	23.506,31
2021	13.460,69	1.639,88	1.298,24	4.373,02	1.093,25	18.790,31	2.869,79	18.585,32
2022	13.121,27	2.090,75	648,85	6.416,44	432,57	22.133,13	2.162,85	16.653,92

Notes: Expressed in standard cubic meter of natural gas

Table XL - *Underground pipelines localization phase leaks estimated emissions*

Table 20 shows the pre-localization methane estimated emissions, expressed in cubic meters, divided in third-party notified leaks and company scheduled inspection leaks.

Pre-localization methane estimated emissions m^3			
Years	TPN	CSI	Total
2018	560.823,85	2.446.718,93	3.007.542,77
2019	560.413,70	3.566.718,94	4.127.132,64
2020	627.221,50	3.244.890,76	3.872.112,27
2021	591.848,45	2.939.011,92	3.530.860,37
2022	441.385,38	2.858.439,42	3.299.824,80
Total	2.781.692,87	15.055.779,97	17.837.472,84

Notes: Estimation derived from Company data related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by pre-localization method: Third party notified (TPN) and company scheduled inspections (CSI)

Table 20 *Pre-localization estimated emissions*

Table 21 shows the pre-localization methane estimated emissions, expressed in cubic meters, divided in third-party notified leaks and company scheduled inspection leaks.

Pre-localization estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	44.172,00	12.422,92	926.931,68	2.024.016,17	3.007.542,77
2019	32.192,72	9.684,81	1.268.936,47	2.816.318,63	4.127.132,64
2020	72.622,38	9.050,50	1.333.991,45	2.456.447,94	3.872.112,27
2021	105.210,20	4.453,45	1.059.965,89	2.361.230,82	3.530.860,37
2022	49.869,55	3.994,50	1.047.230,21	2.198.730,55	3.299.824,80
Total	304.066,85	39.606,18	5.637.055,70	11.856.744,11	17.837.472,84

Notes: Estimation derived from Company data related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 21 *Pre-localization estimated emissions*

Table 22 shows the pre-localization methane estimated emissions, expressed in cubic meters, dividend per share volume of existence phases over the total.

Pre-localization estimated emissions m³ CH_4 - share of leak existence phases					
Years	Latency time	Localization time	Total	% Incubation	% Localization
2018	2.949.021,78	58.520,99	3.007.542,77	98,05%	1,95%
2019	4.022.774,02	104.358,62	4.127.132,64	97,47%	2,53%
2020	3.766.688,95	105.423,32	3.872.112,27	97,28%	2,72%
2021	3.439.408,15	91.452,21	3.530.860,37	97,41%	2,59%
2022	3.207.478,31	92.346,49	3.299.824,80	97,20%	2,80%
Total	17.385.371,22	452.101,62	17.837.472,84	97,47%	2,53%

Notes: Estimation derived from Company data related to the pre-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by leak existence phase and share of the estimation over the total

Table 22 *Pre-localization estimated emissions - share of phases*

Annex II.III.II - Post-localization emission estimation

Table XLI through XLII show the disaggregated scheduling phase estimated emissions results for aboveground leaks, gas meter leaks , underground components leaks and underground pipelines leaks, resulting from the multiplication of the number of leaks by the scheduling time of the leaks.
The values are exhibited divided by priority class, pre-localization method and the year of their elimination.

Source	**Aboveground**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	11,92	1,23	15,09	1,16	18,25	2,61	3.335,81	386,46
2019	9,91	3,74	0,02	0,00	0,01	0,00	2.872,43	249,83
2020	8,05	1,52	1,54	0,64	35,70	4,46	4.844,81	864,56
2021	13,08	3,26	0,00	0,00	0,00	0,00	7.007,52	1.591,94
2022	10,11	2,02	1,02	0,00	2,90	0,00	3.597,55	393,19

Notes: Expressed in standard cubic meter of natural gas

Table XLI - *Aboveground leaks scheduling phase estimated emissions*

Source	**Gas meter**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	8,43	0,70	0,00	0,00	0,00	0,00	196,49	22,49
2019	5,00	0,58	0,00	0,00	0,00	0,00	20,47	2,31
2020	3,43	0,28	0,00	0,00	0,00	0,00	18,30	2,09
2021	3,49	0,36	0,00	0,00	0,00	0,00	23,74	1,54
2022	2,64	0,50	0,00	0,00	0,00	0,00	1,39	0,11

Notes: Expressed in standard cubic meter of natural gas

Table XLII *- Gas meter scheduling phase leaks estimated emissions*

Source	Underground components							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	54,51	2,99	157,18	302,28	977,11	3.419,88	11.057,05	22.330,90
2019	51,75	3,22	262,30	674,49	1.864,77	5.128,11	12.252,45	34.796,94
2020	58,19	2,30	395,73	814,74	1.623,34	5.519,36	13.699,23	28.138,95
2021	60,03	2,07	291,92	368,74	1.520,59	4.561,76	10.895,19	25.876,08
2022	62,10	2,30	151,53	361,35	1.640,32	7.683,62	15.659,25	31.877,75

Notes: Expressed in standard cubic meter of natural gas

Table XLIII - *Underground components scheduling phase leaks estimated emissions*

Source	Underground Pipelines							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	39,79	4,37	254,55	1.299,56	159,38	13.546,98	13.159,37	48.845,80
2019	33,12	7,13	192,59	2.439,51	1.135,27	26.373,27	9.295,22	64.815,30
2020	32,43	3,45	230,73	1.547,24	825,33	19.532,80	6.383,62	55.575,07
2021	45,31	5,52	267,23	900,13	1.328,96	22.841,47	7.744,42	50.154,35
2022	41,86	6,67	95,45	943,87	597,18	30.555,77	7.824,12	60.245,70

Notes: Expressed in standard cubic meter of natural gas

Table XLIV - *Underground pipelines scheduling phase leaks estimated emissions*

Table XLV through XLVIII show the disaggregated repair time estimated emissions results for aboveground leaks, gas meter leaks , underground components leaks and underground pipelines leaks, resulting from the multiplication of the number of leaks by the repair time of the leaks.
The values are exhibited divided by priority class, pre-localization method and the year of their elimination.

Source	**Aboveground**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	5,13	0,53	0,06	0,00	0,03	0,00	10,99	1,27
2019	3,47	1,31	0,05	0,01	0,01	0,00	8,57	0,75
2020	3,30	0,62	0,05	0,02	0,07	0,01	10,96	1,96
2021	8,11	2,02	0,03	0,01	0,04	0,00	20,31	4,61
2022	5,46	1,09	0,02	0,00	0,02	0,00	18,48	2,02

Notes: Expressed in standard cubic meter of natural gas

Table XLV - *Aboveground repair phase leaks estimated emissions*

Source	**Gas meter**							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	3,03	0,25	0,00	0,00	0,00	0,00	2,64	0,30
2019	1,75	0,20	0,00	0,00	0,00	0,00	2,01	0,23
2020	1,30	0,11	0,00	0,00	0,00	0,00	2,01	0,23
2021	1,36	0,14	0,00	0,00	0,00	0,00	1,90	0,12
2022	1,08	0,21	0,00	0,00	0,00	0,00	1,50	0,12

Notes: Expressed in standard cubic meter of natural gas

Table XLVI - *Gas meters repair phase leaks estimated emissions*

Source	Underground components							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	377,21	20,69	20,69	39,79	22,28	77,99	81,17	163,93
2019	277,38	17,26	17,26	44,38	34,52	94,93	61,64	175,06
2020	152,46	6,03	10,24	21,09	12,05	40,98	44,59	91,60
2021	191,50	6,60	13,94	17,61	13,94	41,82	41,09	97,58
2022	292,49	10,83	14,08	33,58	20,58	96,41	60,66	123,50

Notes: Expressed in standard cubic meter of natural gas

Table XLVII - *Underground components repair phase leaks estimated emissions*

Source	Underground Pipelines							
Priority class	A1		A2		B		C	
Pre-localization method	TPN	CSI	TPN	CSI	TPN	CSI	TPN	CSI
2018	241,92	26,57	26,57	135,64	2,80	237,73	82,51	306,25
2019	156,66	33,72	13,05	165,36	14,14	328,55	40,25	280,68
2020	128,75	13,70	15,52	104,09	8,22	194,49	31,05	270,28
2021	195,74	23,85	18,88	63,59	15,90	273,24	41,73	270,26
2022	172,04	27,41	8,51	84,13	5,67	290,21	28,36	218,36

Notes: Expressed in standard cubic meter of natural gas

Table XLVIII - *Underground pipelines repair phase leaks estimated emissions*

Table 23 shows the post-localization methane estimated emissions, expressed in cubic meters, divided in elimination priority classes.

Post-localization estimated methane emissions m^3					
Years	A1	A2	B	C	Total
2018	735,33	2.072,37	16.987,83	91.984,76	111.780,30
2019	557,71	3.504,30	32.175,69	114.884,21	151.121,90
2020	382,63	2.890,31	25.573,06	101.180,96	130.026,96
2021	517,43	1.786,70	28.149,89	95.470,59	125.924,61
2022	587,71	1.558,07	37.621,27	110.447,90	150.214,94
Total	2.780,81	11.811,75	140.507,74	513.968,42	669.068,72

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meters of methane emitted, divided by priority classes: Immediate priority (A1), High priority (A2), Medium priority (B) and low priority (C).

Table 23 *Post-localization estimated emissions*

Table 24 shows the post-localization methane estimated emissions, expressed in cubic meters, divided by leak sources.

Post localization estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	3.487,29	215,59	35.977,21	72.100,20	111.780,30
2019	2.898,10	29,95	51.295,93	96.897,92	151.121,90
2020	5.316,00	25,53	46.580,41	78.105,02	130.026,96
2021	7.958,85	30,03	40.480,41	77.455,33	125.924,61
2022	3.711,17	6,94	53.443,14	93.053,69	150.214,94
Total	23.371,41	308,05	227.777,09	417.612,17	669.068,72

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 24 *Pre-localization estimated emissions*

Table 25 shows the post-localization methane estimated emissions, expressed in cubic meters, dividend per share volume of existence phases over the total.

Post localization estimated methane emissions - shares of leaks existence phases					
Years	Scheduling time	Repair time	Total	% Scheduling	% Repair
2018	110.043,35	1.736,95	111.780,30	98,45%	1,55%
2019	149.490,56	1.631,35	151.121,90	98,92%	1,08%
2020	128.954,46	1.072,50	130.026,96	99,18%	0,82%
2021	124.667,98	1.256,64	125.924,61	99,00%	1,00%
2022	148.819,45	1.395,49	150.214,94	99,07%	0,93%
Total	661.975,80	7.092,92	669.068,72	98,94%	1,06%

Notes: Estimation derived from Company data related to the post-localization phase of methane emissions expressed in cubic meter of methane emitted, divided by leak existence phase and share of the estimation over the total

Table 25 *Post-localization estimated emissions - share of phases*

Annex II.III.III - Total emission estimation

Table 26 shows the total estimated emissions, expressed as cubic meters of methane, divided by source.

Total estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	47.659,29	12.638,51	962.908,89	2.096.116,38	3.119.323,07
2019	35.090,82	9.714,76	1.320.232,40	2.913.216,55	4.278.254,54
2020	77.938,39	9.076,03	1.380.571,85	2.534.552,96	4.002.139,23
2021	113.169,05	4.483,48	1.100.446,30	2.438.686,15	3.656.784,98
2022	53.580,71	4.001,44	1.100.673,34	2.291.784,24	3.450.039,74
Total	327.438,26	39.914,22	5.864.832,80	12.274.356,28	18.506.541,56

Notes: Estimation derived from Company data related to the sum or the different phases of methane emissions expressed in cubic meter of methane emitted, divided by source

Table 26 *Total estimated emissions*

Table 27 shows the methane estimated emissions, expressed in cubic meters, dividend per share volume of existence phases over the total.

Years	Incubation time	Elimination time	Total	Incubation time %	Elimination time %
2018	3.007.542,77	111.780,30	3.119.323,07	96,42%	3,58%
2019	4.127.132,64	151.121,90	4.278.254,54	96,47%	3,53%
2020	3.872.112,27	130.026,96	4.002.139,23	96,75%	3,25%
2021	3.530.860,37	125.924,61	3.656.784,98	96,56%	3,44%
2022	3.299.824,80	150.214,94	3.450.039,74	95,65%	4,35%
Total	17.837.472,84	669.068,72	18.506.541,56	96,38%	3,62%

Notes: Estimation derived from Company data related to the different phases of methane emissions expressed in cubic meter of methane emitted,, divided by leak existence phase and share of the estimation over the total

Table 27 *Total estimated emissions - share of phases*

Annex II.III.IV - Maximum time granted

Table 29 shows the maximum estimated methane emissions, expressed in cubic meters, derived by substituting the Company data relative to latency time and scheduling time with the maximum time granted by the regulator from the minimum required inspection rate and the maximum time granted for leak elimination

Maximum estimated methane emissions m^3					
Years	Aboveground	Gas meter	Components	Pipelines	Total
2018	179.235,60	51.164,07	1.522.334,85	3.275.153,77	5.027.888,28
2019	153.637,82	39.844,07	2.051.016,53	4.450.951,23	6.695.449,64
2020	232.061,86	36.797,52	2.162.693,80	3.921.456,73	6.353.009,92
2021	323.923,86	27.598,81	1.819.654,55	3.982.408,72	6.153.585,94
2022	233.372,50	22.396,53	1.882.375,99	3.883.756,94	6.021.901,96
Total	1.122.231,64	177.800,99	9.438.075,73	19.513.727,38	30.251.835,74

Notes: Estimation derived by substituting the Company data relative to latency time and scheduling time to the maximum time granted by the regulator from the minimum required inspection frequency and the maximum time granted for leak elimination.

Table 29 *Maximum estimated emissions*

Annex III - Mitigation strategies in leak repair

Annex III exhibits the data and the results for what regards chapter 4 and will be following the sequence present in the document

Annex III.I - Prioritizing environmental externalities in leak repair

Annex III.I.I - Prioritizing emissions

Table 35 shows the number of the leaks divided in priority classes and source of emissions exhibiting their scheduling time, repair time and elimination time, expressed in hours.

	Priority	Source	Leaks number	Scheduling time (h)	Repair time (h)	Elimination time (h)
Current leak elimination overview	Immediate priority (A1)	Aboveground	6.484	1,0	0,5	1,5
		Pipelines	955	1,0	4,6	5,64
		Components	1.132	1,0	4,6	5,56
		Gas meter	5.078	1,0	0,4	1,4
	High priority (A2)	Aboveground	59	25,7	0,5	26,2
		Pipelines	592	58,9	4,6	63,5
		Components	227	70,5	4,6	75,11
	Medium priority (B)	Aboveground	40	96,7	0,5	97,2
		Pipelines	1313	383,7	4,6	388,4
		Components	440	333,8	4,6	338,4
	Low priority (C)	Aboveground	16.478	149,6	0,5	150,1
		Pipelines	1478	962,8	4,6	967,4
		Components	931	974,9	4,6	979,5
		Gas meter	5.923	7,7	0,4	8,1

Notes: In order: Priority classes divided in A1, A2, B and C; source of the emission, divided in aboveground, underground pipelines, underground components and gas meters; leak number relatively to the priority class and the source; scheduling time expressed in hours depending on the priority class and the source; the repair time, expressed in hours, relative to the source of the leak; the elimination time as the sum of the scheduling time and the repair time, expressed in hours.
All time values are exhibited as the average of the yearly values, for the years from 2018 to 2022.

Table 35 *Current leak elimination time overview*

Annex III.I.II - Budget constraint model

Table XLIX shows the yearly cost invoices for the costs regarding leak elimination.
The data related to the network has been gathered from the Company dataset "Dati economici emissioni metano; Pronto intervento".

Cost invoice	Year considered					
	2022	2021	2020	2019	2018	2018-2022
Fleet	250.687,97 €	162.503,94 €	174.864,70 €	215.243,82 €	233.189,46 €	1.036.489,89 €
Materials	401.187,84 €	398.894,39 €	248.124,45 €	287.496,52 €	258.158,67 €	1.593.861,87 €
Services	1.526.686,88 €	1.365.362,62 €	1.659.175,89 €	2.075.494,88 €	1.772.331,39 €	8.399.051,66 €
Management	2.486,00 €	12.274,54 €	- 17.683,09 €	- 115.572,41 €	3.375,60 €	- 115.119,36 €
Personnel	3.417.749,16 €	3.117.857,37 €	2.722.830,61 €	3.216.955,59 €	3.665.542,07 €	16.140.934,80 €
Total	5.598.797,85 €	5.056.892,86 €	4.787.312,56 €	5.679.618,40 €	5.932.597,19 €	27.055.218,86 €

Notes: Invoice costs divided by years.

***Table XLIX -** Leak elimination costs*

Table 41 shows the number of the leaks divided in priority classes and source of emissions exhibiting their repair time, the personnel workload to repair such leaks, the amount of budget that is allocated for that precise priority class and the share percentage over the total personnel expenses.

	Priority	**Source**	**Leaks number**	**Repair time (h)**	**Personnel workload (h)**	**Priority budget (h)**	**Share percentage**
Current time budget overview	Immediate priority (A1)	Aboveground	6.484	0,5	3.047,48	15.351,42	31,78%
		Pipelines	955	4,6	5.990,50		
		Components	1.302	4,6	4.393,96		
		Gas meter	5.078	0,4	1.919,48		
	High priority (A2)	Aboveground	59	0,5	27,73	3.795,95	7,86%
		Pipelines	592	4,6	1.044,43		
		Components	227	4,6	2.723,79		
	Medium priority (B)	Aboveground	40	0,5	18,80	8.084,35	16,74%
		Pipelines	1.313	4,6	2.024,44		
		Components	440	4,6	6.041,11		
	Low priority (C)	Aboveground	16.478	0,5	7.744,66	21.067,36	43,62%
		Pipelines	1.478	4,6	2.238,89		
		Components	931	4,6	4.283,53		
		Gas meter	5.923	0,4	6.800,28		
Total	All	All	41.300		48.299,09	48.299,09	100%

Notes: The table shows how the current time budget is formed, dividing every priority class in sources and exhibiting the number of leaks related to every source for every priority.

***Table 41** Current time budget overview*

Table 50 shows the total elimination time divided by the source of the leak, the budget model priorities, the operating pressure, the pre-localization method and the number of leaks that belong to each category.

Budget model priorities	**Source**	**Operating pressure**	**Pre localization**	**Number**	**Elimination time (h)**	**Total elimination time (h)**
Immediate priority	Under ground	MP	TPN	1.333	5,60	7.464,80
		LP	TPN	818		4.580,80
		MP	CSI	1.185		6.636,00
High priority				825	69,31	57.176,63
Medium priority				1.143	363,40	415.366,20
		LP	CSI	614		223.127,60
Low priority				1.320	973,45	1.284.954,00
	Above ground	LP	TPN	19.766	150,10	2.966.876,60
			CSI	3.295		494.579,50
	Gas meter	LP	TPN	9.976	8,10	80.805,60
			CSI	1.025		8.302,50
Total				41.300		5.549.870,23

Notes: The table shows how the total elimination time is estimated, dividing the results by new priority, emission source, operating pressure and pre-localization method. The new total elimination time, expressed in hours is the result of the multiplication between the current elimination time, expressed in hours and the number of leaks belonging to the new priority classes divided by the factore aforementioned.

Table 50 *Budget constraint model total elimination time*

Table 51 shows the estimated natural gas emissions, expressed in standard cubic meters, dividing them by the priorities of the budget model, the source, the operating pressure, the pre-localization method, the relative emissions factors and the number of leaks belonging to each category.

Budget model priorities	**Source**	**Operating pressure**	**Pre localization**	**Number**	**Total elimination time (h)**	**Emission factors (scm/h)**	**Estimated emissions (scm)**
Immediate priority	Underground	MP	TPN	1.333	7.464,80	0,24	1.791,55
		LP	TPN	818	4.580,80		1.099,39
		MP	CSI	1.185	6.636,00		1.592,64
High priority				825	57.176,63		13.722,39
Medium priority				1.143	415.366,20		99.687,89
		LP	CSI	614	223.127,60		53.550,62
Low priority				1.320	1.284.954,00		308.388,96
	Above ground	LP	TPN	19.766	2.966.876,60	0,01	29.668,77
			CSI	3.295	494.579,50		4.945,80
	Gas meter	LP	TPN	9.976	80.805,60	0,005	404,03
			CSI	1.025	8.302,50		41,51
Total				41.300	5.549.870,23		514.893,55

Notes: The table shows how the emissions related to the priority classes changes are estimated, dividing the results by new priority, emission source, operating pressure and pre-localization method. The new estimated emissions, expressed in standard cubic meters of natural gas, is the result of the multiplication between the total elimination time, expressed in hours and the emission factors of every source, expressed in standard cubic meter per hours grouped by the factors aforementioned.

Table 51 *Budget constraint model estimated emissions*

Annex III.I.II - Budget and safety constraint model

Table 64 shows the total elimination time divided by the source of the leak, the budget and safety model priorities, the operating pressure, the pre-localization method and the number of leaks that belong to each category.

Budget and safety constraint model priorities	**Source**	**Operating pressure**	**Pre localization**	**Number**	**Elimination time (h)**	**Total elimination time (h)**
High priority	Underground	MP	TPN	482	69,31	33.405,01
		LP	TPN	305		21.138,03
		MP	CSI	38		2.633,59
Medium priority				1.757	363,40	638.493,80
Low priority				801	973,45	779.733,45
		LP	CSI	1.598		973,45
	Aboveground	LP	TPN	14.459	150,10	2.170.295,90
			CSI	2.118		317.911,80
	Gas meters	LP	TPN	5.381	8,10	43.586,10
			CSI	542		4.390,20
Total				27.481		4.012.561,33

Notes: The table shows how the total elimination time is estimated, dividing the results by new priority, emission source, operating pressure and pre-localization method. The new total elimination time, expressed in hours is the result of the multiplication between the current elimination time, expressed in hours and the number of leaks belonging to the new priority classes divided by the factore aforementioned.

Table 64 *Budget and safety constraint model total elimination time*

Table 65 shows the estimated natural gas emissions, expressed in standard cubic meters, dividing them by the priorities of the budget and safety model, the source, the operating pressure, the pre-localization method, the relative emissions factors and the number of leaks belonging to each category.

Budget and safety constraint model priorities	Source	Operating pressure	Pre localization	Number	Total elimination time (h)	Emission factors (scm/h)	Estimated emissions (scm)
High priority	Underground	MP	TPN	482	33.405,01	0,24	8.017,20
		LP	TPN	305	21.138,03		5.073,13
		MP	CSI	38	2.633,59		632,06
Medium priority				1.757	638.493,80		153.238,51
Low priority				801	779.733,45		187.136,03
		LP	CSI	1.598	1.555.573,10		373.337,54
	Above ground	LP	TPN	14.459	2.170.295,90	0,01	21.702,96
			CSI	2.118	317.911,80		3.179,12
	Gas meters	LP	TPN	5.381	43.586,10	0,01	217,93
			CSI	542	4.390,20		21,95
Total				27.481	5.567.160,98		752.556,43

Notes: The table shows how the emissions related to the priority classes changes are estimated, dividing the results by new priority, emission source, operating pressure and pre-localization method. The new estimated emissions, expressed in standard cubic meters of natural gas, is the result of the multiplication between the total elimination time, expressed in hours and the emission factors of every source, expressed in standard cubic meter per hours grouped by the factors aforementioned.

Table 65 *Budget and safety constraint model estimated emissions*

Annex III.II - Mitigation strategies in fugitive emissions detection

Annex III.II.I - Increasing inspections

Table 72 shows the current amount of network inspected by various time variables: yearly monthly and daily, expressed in kilometers.

Year	Yearly inspected network (km)	Monthly inspected network (km)	Daily inspected network (Km)
2018	7.636,91	737,09	20,92
2019	7.590,56	695,66	20,79
2020	7.866,35	655,53	21,55
2021	8.347,89	632,55	22,87
2022	8.845,14	636,41	24,23
Average	8.057,37	671,45	22,07

Notes: The table shows the yearly inspected network over the analyzed years, as well as the monthly inspected network and the daily inspected network all expressed in kilometers..

***Table** 72 Network inspected*

Table LX shows the personnel costs, the hours worked , the hourly cost and the full time equivalent for leak detection procedure, company scheduled inspections, divided by every year with the total placed in the last row.
The data related to the network has been gathered from the Company dataset "Dati economici emissioni metano; RFP".

Years	Personnel cost	Workload	Hourly cost	Full time equivalent
2022	329.503,97 €	8.863,00	37,18 €	5,3
2021	417.124,87 €	11.195,00	37,26 €	6,7
2020	376.973,31 €	10.014,00	37,64 €	6,0
2019	429.211,81 €	11.337,00	37,86 €	6,8
2018	445.654,53 €	11.537,00	38,63 €	6,9
Total	1.998.468,49 €	52.946,00	37,75 €	31,8

Notes: Personnel costs are expressed in euros, hours worked expressed in hours and the hourly cost expressed in euros per hour.

***Tab LX -** Scheduled inspections costs*

Annex III.II.II - Citizen engagement

Table from LXI to LXIII show the economic transfer relative to equation:

$$Inc = (P_{disp} * Q_{max}) * Nu_j * Val * \left(1 + \varepsilon_{PC_{j,t}} + \varepsilon_{P_{j,t}}\right)^z$$

divided for every distribution network managed by the company (distribution network 1 to 50), divided in LivEr, P_{Disp}, and the singular economic transfer related to every distribution network.
The articles to which the different factors refer to are shown between brackets and different from 2018/2019 and 2020 due to the different version of the norm accounting period of regulation, while 2018 and 2019 are regulated by *Delibera 367/14* that was responsible for the years from 2014 to 2019 while *Delibera 569/19* is responsible for the five years from 2020 to 2025.
It can be seen as negative values for P_{Disp} lead to negative monetary transfers.

Distribution network	**LivEff 2018 (art. 32.2)**	**PDISP 2018 (art. 32.7)**	**Economic transfer (art. 32.17 e 32.19)**
Distribution network 1	16,82	11,13	€ 22.594,94
Distribution network 2	11,11	10,00	€ 6.615,74
Distribution network 3	30,48	2,46	€ 2.695,97
Distribution network 4	28,07	20,10	€ 13.125,56
Distribution network 5	14,90	13,65	€ 301.927,44
Distribution network 6	19,59	13,44	€ 24.286,56
Distribution network 7	15,94	11,44	€ 9.282,42
Distribution network 8	9,06	5,95	€ 434,89
Distribution network 9	7,50	7,54	€ 0,00
Distribution network 10	7,50	1,63	€ 9.053,03
Distribution network 11	10,85	8,76	€ 105.999,73
Distribution network 12	22,31	11,03	€ 7.206,91
Distribution network 13	13,73	10,28	€ 203.483,87
Distribution network 14	7,98	5,01	€ 109.151,73
Distribution network 15	7,74	6,47	€ 15.146,24
Distribution network 16	27,29	16,02	€ 37.617,70
Distribution network 17	12,08	20,66	-€ 5.610,53
Distribution network 18	8,38	8,80	-€ 30.709,14
Distribution network 19	10,78	7,70	€ 12.675,34
Distribution network 20	12,78	11,89	€ 2.044,21
Distribution network 21	13,36	13,23	€ 0,00
Distribution network 22	19,98	11,15	€ 41.360,16
Distribution network 23	8,15	3,87	€ 9.753,84
Distribution network 24	8,26	5,71	€ 5.585,36

Distribution network 25	8,89	7,38	€ 89.869,08
Distribution network 26	27,22	4,75	€ 2.788,70
Distribution network 27	16,92	11,10	€ 5.787,04
Distribution network 28	80,27	71,43	€ 273,34
Distribution network 29	9,91	4,78	€ 8.687,84
Distribution network 30	9,52	9,59	€ 0,00
Distribution network 31	34,07	14,48	€ 8.690,69
Distribution network 32	15,13	7,23	€ 81.149,15
Distribution network 33	17,08	6,73	€ 15.561,56
Distribution network 34	13,51	14,02	-€ 401,64
Distribution network 35	13,55	6,32	€ 67.330,16
Distribution network 36	12,14	63,53	-€ 1.407,60
Distribution network 37	24,57	12,36	€ 15.003,36
Distribution network 38	16,57	4,99	€ 7.507,58
Distribution network 39	8,63	6,67	€ 6.267,13
Distribution network 40	10,22	7,96	€ 236.861,04
Distribution network 41	13,13	9,76	€ 18.025,99
Distribution network 42	8,01	17,61	-€ 13.353,98
Distribution network 43	8,97	3,56	€ 21.244,81
Distribution network 44	16,45	5,48	€ 3.623,33
Distribution network 45	7,50	1,57	€ 63.821,33
Distribution network 46	27,79	19,70	€ 8.455,75
Distribution network 47	11,03	12,92	-€ 17.938,81
Distribution network 48	8,54	9,67	-€ 3.274,07
Distribution network 49	8,35	7,98	€ 0,00
Distribution network 50	10,61	9,96	€ 5.065,09
Total			€ 1.533.358,84

Notes: The economic transfer is expressed in euros

Tab LXI - *2018 Company economic transfer*

Distribution network	LivEff 2019 (art. 42.2)	PDISP 2019 (art. 42.7)	Economic transfer (art. 42.8 e 45)
Distribution network 1	7,50	0,53	€ 9.050,08
Distribution network 2	7,58	0,00	€ 0,00
Distribution network 3	11,24	-0,60	-€ 5.570,78
Distribution network 4	11,88	0,44	€ 7.518,16
Distribution network 5	8,34	0,26	€ 7.712,80
Distribution network 6	15,64	0,56	€ 16.636,88
Distribution network 7	10,34	0,35	€ 15.709,29
Distribution network 8	28,35	1,20	€ 2.682,72
Distribution network 9	26,10	1,20	€ 14.751,65
Distribution network 10	13,86	0,58	€ 1.051.804,36
Distribution network 11	18,22	1,20	€ 40.007,97
Distribution network 12	14,83	0,21	€ 3.561,20
Distribution network 13	8,43	0,66	€ 692,58
Distribution network 14	7,50	0,13	€ 13.090,02
Distribution network 15	10,09	0,62	€ 236.434,43
Distribution network 16	20,75	0,68	€ 4.038,98
Distribution network 17	12,77	0,95	€ 472.828,67
Distribution network 18	7,74	0,47	€ 146.204,44
Distribution network 19	25,38	0,47	€ 16.455,57
Distribution network 20	7,93	-0,07	-€ 37.969,28
Distribution network 21	10,02	0,24	€ 7.414,91
Distribution network 22	12,43	0,34	€ 4.921,47
Distribution network 23	18,58	0,77	€ 26.831,89
Distribution network 24	7,82	0,53	€ 9.055,54
Distribution network 25	7,87	0,43	€ 7.007,50
Distribution network 26	8,26	0,18	€ 81.754,31
Distribution network 27	25,31	1,20	€ 2.795,33
Distribution network 28	15,74	1,20	€ 8.843,04
Distribution network 29	74,65	-0,60	-€ 139,10
Distribution network 30	9,22	-0,50	-€ 6.403,87
Distribution network 31	8,85	0,22	€ 95.269,29
Distribution network 32	31,68	1,15	€ 8.230,87
Distribution network 33	14,07	0,77	€ 67.130,86
Distribution network 34	15,88	-0,39	-€ 3.975,88

Distribution network 35	12,56	0,00	€ 0,00
Distribution network 36	12,60	-0,60	-€ 41.946,48
Distribution network 37	11,29	-0,60	-€ 1.377,79
Distribution network 38	22,85	1,16	€ 14.521,84
Distribution network 39	15,41	-0,60	-€ 2.969,08
Distribution network 40	8,04	-0,60	-€ 14.453,57
Distribution network 41	9,51	0,20	€ 155.278,84
Distribution network 42	12,21	-0,60	-€ 24.101,42
Distribution network 43	7,75	-0,49	-€ 10.923,11
Distribution network 44	15,30	0,83	€ 2.535,14
Distribution network 45	7,50	0,53	€ 63.671,28
Distribution network 46	25,85	0,97	€ 7.516,98
Distribution network 47	10,26	-0,32	-€ 22.980,18
Distribution network 48	8,01	-0,12	-€ 2.526,06
Distribution network 49	7,91	0,24	€ 28.969,05
Distribution network 50	9,87	0,51	€ 29.922,20
Total			€ 2.505.513,54

Notes: The economic transfer is expressed in euros

***Tab LXI -** 2019 Company economic transfer*

Distribution network	LivEff 2020 (art. 42.2)	PDISP 2020 (art. 42.7)	Economic transfer (art. 42.8 e 45)
Distribution network 1	9,95	0,30	€ 10.021,33
Distribution network 2	12,27	-0,48	-€ 19.514,59
Distribution network 3	2,51	0,61	€ 1.727,91
Distribution network 4	9,60	0,31	€ 622.976,70
Distribution network 5	13,70	-0,48	-€ 10.789,39
Distribution network 6	3,58	0,94	€ 18.733,09
Distribution network 7	12,18	-0,60	-€ 54.127,11
Distribution network 8	8,00	-0,07	-€ 1.092,71
Distribution network 9	4,88	0,35	€ 174.086,53
Distribution network 10	11,12	0,00	€ 0,00
Distribution network 11	5,70	0,26	€ 148.753,63
Distribution network 12	4,69	0,38	€ 134.399,30
Distribution network 13	9,61	-0,28	-€ 23.109,03
Distribution network 14	17,00	-0,20	-€ 4.817,55
Distribution network 15	7,44	0,39	€ 329.896,45
Distribution network 16	13,95	-0,60	-€ 16.830,98
Distribution network 17	13,42	-0,34	-€ 5.371,76
Distribution network 18	8,34	0,49	€ 9.241,48
Distribution network 19	8,10	0,46	€ 17.577,10
Distribution network 20	4,51	0,40	€ 7.524,99
Distribution network 21	5,39	0,28	€ 5.062,39
Distribution network 22	4,97	0,34	€ 141.736,38
Distribution network 23	2,39	0,53	€ 1.602,59
Distribution network 24	6,71	0,45	€ 4.359,23
Distribution network 25	50,00	1,20	€ 291,46
Distribution network 26	14,60	-0,60	-€ 7.012,41
Distribution network 27	6,87	0,13	€ 59.611,11
Distribution network 28	34,78	-0,60	-€ 3.896,12
Distribution network 29	20,89	-0,60	-€ 35.609,10
Distribution network 30	11,78	0,00	€ 0,00
Distribution network 31	39,89	-0,60	-€ 3.245,76
Distribution network 32	13,07	-0,32	-€ 20.212,24
Distribution network 33	26,57	0,57	€ 1.420,30
Distribution network 34	19,80	-0,58	-€ 11.526,86

Distribution network 35	24,63	-0,60	-€ 2.585,91
Distribution network 36	9,89	-0,15	-€ 3.339,08
Distribution network 37	7,05	0,14	€ 114.710,09
Distribution network 38	6,89	0,66	€ 28.902,33
Distribution network 39	3,48	1,20	€ 29.291,33
Distribution network 40	14,18	-0,60	-€ 16.135,46
Distribution network 41	1,80	0,53	€ 1.796,19
Distribution network 42	4,59	0,39	€ 50.824,61
Distribution network 43	13,66	1,00	€ 21.786,34
Distribution network 44	13,12	-0,20	-€ 13.111,67
Distribution network 45	7,55	0,07	€ 1.665,82
Distribution network 46	3,99	0,47	€ 61.991,60
Distribution network 47	7,05	0,06	€ 4.580,73
Total			€ 1.752.243,28

Notes: The economic transfer is expressed in euros

Tab LXII - *2020 Company economic transfer*

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