Post-meter gas leakage reduction

Cost and Benefit Analysis

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10/04/2024

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1. General information

Reducing methane emissions is a priority but also an opportunity.

With the aim of preventing climate change, the European Union has set ambitious targets for the reduction of its greenhouse gas emissions. The EU aims to achieve climate neutrality by 2050 and this goal is stated in the European Climate Act, together with the intermediate target of a 55% reduction in CO2 emissions by 2030

Methane gas leaks are not only a threat to safety but also relevant to greenhouse gas pollution. In fact, methane has a shorter average residence time in the atmosphere (10 to 12 years) than carbon dioxide (hundreds of years), but its greenhouse effect is 80 times more significant from a climate perspective than carbon dioxide over a 20-year period. The amount of methane in the atmosphere worldwide has increased significantly over the last decade.

The methane gas distribution systems downstream of the meter (post meter) are the responsibility of the user and may be subject to gas leaks that are not detected by the distributors during the leak detection activities carried out periodically in the sections of the grid under their purview. Most of these leaks are small (fugitive) and are hardly perceived even by the user Identifying leaks occurring in one's own systems (post-meter) could allow the user to eliminate or reduce these leaks with benefits on pollution, climate, safety and methane consumption.

The study that is the subject of this paper stems from Pietro Fiorentini's marketing need to define a strategy for the technological evolution of its products that can contribute to the fight against climate change. The purpose of the study is not to assess whether and how much it is worthwhile to invest in reducing these types of leaks, since investing in preventing climate change is essential and unavoidable. The study proposes a method for evaluating and comparing different possible solutions considering the economic effort to be made and the benefits that each solution can offer, thus facilitating the identification of the most effective solution and the prioritisation of investments.

Detecting leaks occurring in user installations, at least those above a minimum flow, is technically possible and different solutions can be used for this purpose. As a solution, the study investigates the use of smart meters that are installed on all gas users and used to meter the user's consumption.

This paper performs a cost-benefit analysis (CBA) aimed at assessing the return on investment (ROI) of different solutions that investigate the use of the smart meter as an element for the detection and measurement of post-meter leaks. The paper also evaluates and compares an alternative hypothesis, not based on the use of the smart meter, which involves periodic verification of the tightness of users' installations.
The analysis calculates the *ROI* (Return of Investment) as:

$$ROI = \frac{Benefits - Costs}{Costs}$$

"*Benefits* " and "*Costs*", being the **total** benefits and costs attributable to the distributor, society, the seller in an "*observation period*" fixed at 15 years: benefits and costs are in any case updated.
The analysis calculates ROIcs as the ratio of the difference between the benefit and the unit cost per user related to the function and the sum of the unit cost and the 'Standard Cost' of the smart meter as defined by ARERA[1]. ROIcs is an economic indicator of the usefulness of the function in the context of smart metering.

$$ROIcs = \frac{Unit_{benefit} - Unit_{cost}}{Cost_{standard} + Unit_{cost}}$$

The analysis calculates the 'Ecological Cost' (Eco_Cost), i.e. the cost that must be incurred to reduce CO2 equivalent emissions by one tonne; expressed in € /tonCO_2eq. The Eco_Cost is a measure of the efficiency of the solution and is a significant indicator when comparing emission reduction solutions. The lower the Eco_Cost, the more efficient the solution.

The analysis calculates the avoided emissions (%AE) as the percentage ratio between the tonnes of CO2 equivalent potentially avoided with the solution compared to the assumed tonnes emitted by the grid users of the reference scenario. The %AE indicator is significant for the efficacy of the solution.

The analysis involves the definition of a reference scenario in which all variables with a known value are considered2 or more likely on the basis of estimates or considerations that will be indicated. Variables not known and significant to the CBA will be subject to sensitivity analysis in the range of variability considered permissible or of interest.

Compared to the 2003 edition, this edition of the paper corrects calculation errors and evaluates the results obtained with two different probability distributions of occurrence of post-meter methane gas leaks in systems.

[1] The 'Standard Cost' is defined by ARERA in resolution 737/2022/R/gas
[2] For these values, the sources that they are generated from will be cited

2. Types of leaks

Post-meter fugitive leaks, i.e. leaks occurring in the user's system and downstream of the meter, may be released from the pipeline at joints and fittings as a result of degradation over time of the system's component materials and sealing materials.
The user's system may be more susceptible to fugitive leaks because:

- it is not protected (e.g. with cathodic protection);
- it is not inspected regularly but only occasionally;
- it is not subject to maintenance except after malfunctions;
- leaks are detected by odorant and reactivity to the odour, which is subjective and in any case dependent on the environment where the leak occurs (volume, humidity, etc.); generally speaking, this detection occurs with leak flow rates of at least 10-30 l/h (olfactory threshold 0.03-0.08 mg/Nm^3 and odorant concentration 10 mg/Nm^3).

Theoretically, all installations are subject to leakage: the connection to gas-using equipment, the need to make joints and bends, holes in pipes due to corrosion, even gas oozing through the pipe material are all causes of fugitive gas emissions. Obviously, the extent (i.e. the flow) of these leaks is dependent on the cause and can reach very high values[3]. Gas leakage is a dynamic phenomenon: a system that is not leaking today may be subject to leakage tomorrow; an insignificant leak over time may turn into a major leak, but a gas leak is unlikely to stop spontaneously. A system that has been repaired because it is leaking, may revert to leakage over time, and therefore the periodic inspection of systems is necessary, all the better if it is carried out continuously.

What is the average flow of post-meter leaks in Italy?

There are no official statistics available on the value of the average post-meter leakage flow, but an attempt has been made to answer this question by investigating the occasional leakage in domestic installations. Some distributors have carried out checks when reactivating systems following closure for technical reasons or for arrears, checks carried out in accordance with the requirements of **UNI 11137**[4]. To this end, it is useful to remember that the UNI 11137 standard requires that a system with a leakage value greater than 1 dm^3/h, but not greater than 5 dm^3/h, be considered to have a 'tightness suitable for temporary operation' and can continue to operate for the time necessary, but no longer than 30 days, to carry out the work to restore tightness. On the other hand, a system with a leakage value of more than 5 dm^3/h cannot continue to operate and must be taken out of service. According to information provided by some distributors, more than 5 % (5%-15%) of the systems subjected to such checks were considered suitably tight for temporary operation (leaks of more than 1 dm^3/h but not more than 5 dm^3/h) or not suitably tight for operation (leaks of more than 5 dm^3/h).

[3] On a domestic user, the disconnection of a pipe can generate leaks even greater than 10 m3/h
[4] Standard UNI 11137:2019: "Gas plants for civil uses - Criteria for test and restoration of the tightness of gas installations - General prescriptions and requirements for the second and third gas family"

The estimate of overall post-meter fugitive emissions of natural gas is performed with the emission factor 36 kg CH_4/TJ of distributed energy in dwellings, as reported in the national greenhouse gas emissions inventory (ISPRA, Italian Greenhouse Gas Inventory 1990-2021 National Inventory. Report 2023 - Reports 383/2023, page 131). In 2021, the estimated natural gas leaks in homes were 42.4 Mm3 out of 20,560 Mm^3 of natural gas distributed in the residential sector (~0.13% of the total gas distributed and ~0.20% of the gas distributed in the residential sector), corresponding[5] to **25.6 kt CH4** or approximately **716.8 kt CO2eq** using **28** as the equivalence factor between one tonne of methane and one tonne of CO2, as required by the UNFCCC by Table 19 submission 2023. Natural gas leaks along the entire distribution segment in 2021 were 148 Mm3 out of 34,213 Mm3 of gas distributed.

The total number of users served by the distribution grids[6] in Italy amounts to **24.1 Million**, of which the users with meters up to and including G6 (Qmax = 10 m^3/h) that are the subject of this study amount to **23.6 Million**: of these, in 2022, 19.1 Million were already equipped with smart meters. Since the total post-meter leakage depends mainly on the number of users served, the amount of natural gas that can be attributed to post meter leakage in plants with meters of gauge less than or equal to G6 can be estimated at approximately **41.5 Mm^3.** These leaks correspond to approx. **702 $KtCO_2eq$** per year and an average leak per user - μ - of about **0.20 dm^3/h.** The emission factor[7] according to ISPRA estimates would be 1.06 kg of methane emitted per user per year.

IPCC[8] estimates the emission factor by relating emissions to the number of user devices using the gas, which is 3.2 kg of methane per device. Applying the same criterion in Italy, considering that the total number of domestic users in question for the analysis is about 47 million (Table 20) the total methane leaks should be about 150Kt.

EPA, in its 2021 Inventory[9], applies the estimates of the IPCC of 2019 and on the basis of some studies and field tests (100 users in Boston, 64 in California) considers the emission factor of 2.54 Kg (CH_4)/user for domestic and commercial users as the most tenable, considering unburnt methane emissions included (estimated at about 0.43 Kg(CH_4)/user).

According to the Climate Change National Inventory Report, Germany - 2023, which reports the results of an as yet unpublished study by GWI [10], relevant fugitive emissions[11] amount to more than 41 Kton of methane per year, of which, according to the study, more than 39 Kton are fugitive from start-stop processes.

The difference in these estimates warrants an industry study to further investigate the subject and through direct measurements arrive at more realistic estimates of the amount of gas emitted by post-meter plants and emission factors. Pending such estimates for the purpose of the analysis in this paper, we refer to the average value per user derived from the more conservative estimates provided by ISPRA.

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[5] Considering an average of 93% methane in natural gas and a density of 0.65 at 15°C and 1.01325 bar

[6] Source ARERA - Annual Report 2022

[7] With 93% methane in natural gas and a density of 0.65

[8] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Vol 2, Chapter 4, Section 4.2

[9] Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2020: Updates Under Consideration for Post-Meter Emissions; IPCC considers an emission factor for domestic and commercial users of 3.2E-3 tonnes of methane per appliance.

[10] SGWI is a research and service institute for the German gas industry; the study was commissioned by the German Technical and Scientific Association for Gas and Water (DVGW) (Brandes, 2022)

[11] 13 Million residential and commercial users

To determine the probability distribution of leaks downstream of the meter, it is necessary to define the standard deviation -σ - of the leak distribution, in addition to the mean value. In this regard, it must be considered that fugitive leaks should have a flow (q_{leak_max}) of no more than 9-12 dm^3/h. Greater leakages, in fact, being mostly within the olfactory threshold, would generally be detected by the user and therefore not persistent as they would be resolved by the distributor through emergency response activities.

If we consider a flow q_{leak_max} conservatively contained within 10 dm^3/h and assume that more than 99% of the flows to be intercepted are contained within q_{leak_max}, the result is that **σ = 2.2 dm^3/h.**[12]

Also drawing from the draft 'European regulation for reducing methane emissions in the energy sector' [13]three minimum leakage detection thresholds of 1.5 - 7.5 - 25.3 dm^3/h respectively could be envisaged, to which different levels of alert should be attributed. In the analysis, the thresholds 1 dm^3/h and 5 dm^3/h are taken into account, which represent the limits of acceptability defined by UNI 11137.

Two distributions were evaluated for the probability function: the typical normal distribution and the Gumbel distribution. The lognormal distribution is the probability distribution of a random variable whose logarithm follows a normal distribution.
The Gumbel distribution is a continuous probability distribution with two parameters ϴ1 and ϴ2 (functions of μ and σ), used to describe extreme values such as maxima or minima[14] of continuous stochastic series. The larger -σ- is, the more the two distributions tend towards the normal distribution (Figure 1). The Gumbel and Lognormal versus Normal distribution functions are asymmetrical (mean and median do not coincide) and tend to emphasise smaller leaks; they also provide more realistic values than Normal and have been used for cost-benefit analysis. The reference scenario adopts the Gumbel-type probability distribution, which in our opinion is more precautionary than the lognormal distribution[15]; however, in the range of leaks considered, the two distributions tend to have comparable results with regard to the probability of leakage (Figure 2).

[12] The coefficient of variation Cv= σ/ μ=10.9 indicates that the mean is unrepresentative of the series
[13] At the time of writing this paper, the Regulation does not require applicability to meters
[14] Post-meter leaks are to be found among the persistent minimum flows
[15] If, for example, one considers the average annual contribution of gas lost by users with a leakage flow of less than 1dm3/h, the Gumbel distribution provides 220 dm3/y less than that provided by the lognormal distribution of 860 dm3/y

Figure 1 Comparison of Gumbel Distribution and Normal Distribution

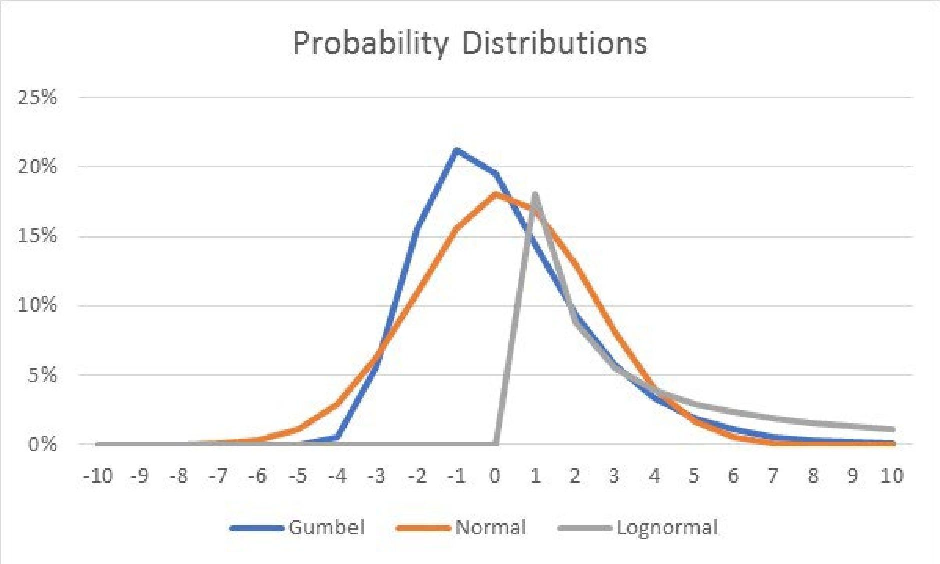


Figure 2- Gumbel and Lognormal leak probability distribution

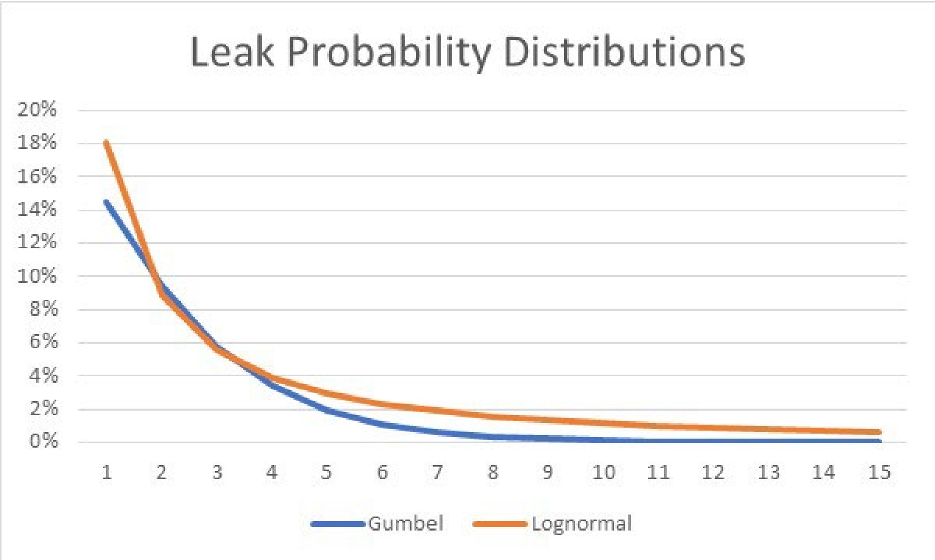


Table 1 summarises the results of the calculations considering different leak flows with the two different probability functions.

The following considerations emerge from the elaborations:

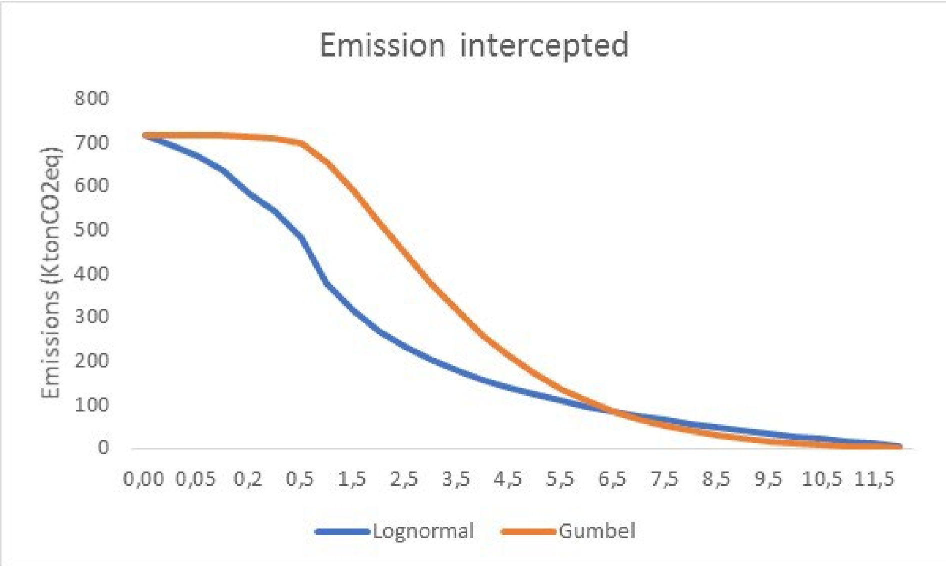
	Gumbel	Lognormal
Users without leakage (<0,02 dmc/h)	54%	52%
Users with leakage < 1dmc/h	70%	97%
Users with leakage> 3dmc/h	10%	1%
User with leakage > 5dmc/h	3%	0,5%

More than half of the plants are practically leak-free and more than 70-96% would have a 'seal fit for operation'.

Both distributions show how few users contribute to a high number of leaks. For example, according to Table 1, with Gumbel's distribution, 30% of users with leaks greater than 1 dm^3/h would be responsible for more than 90% of the leaks, while a little over 3% of users with leaks greater than 5 dm^3/h would contribute almost 24% of the total leaks. According to the lognormal distribution, there would be a little more than 3% of users with a leak of more than 1 dm^3/h, but they contribute almost 53% of the total leaks.

According to the two leakage probability distribution hypotheses, if the smart meters of all users considered had the ability to measure flows greater than or equal to 1 dm^3/h,[16] 22-39 Mm3 of gas could be intercepted, which, being definitely attributable to fugitive leaks, would correspond to 377-654 ktCO_2eq of emissions. In Figure 3, the relationship between minimum leakage flow and quantity of correlated emissions is shown according to the two different distributions with $\sigma = 2.2$ dm^3/h.

Figure 3 - Intercepted emissions in relation to minimum measurable leakage flow



[16] Respectively according to the Lognormal or Gumbel distribution

Table 1- Processing results

Gumbel Distribution						Lognormal Distribution					
leak (dmc/h)	p(x)	F(x) [Users <]	1-F(x) [Users >]	%Tot Leakage <	%Tot Leakage >	leak (dmc/h)	p(x)	F(x) [Users <]	1-F(x) [Users >]	%Tot Leakage <	%Tot Leakage >
0,00	19,6%	53,2%	46,8%	0,00%	100,00%	0,00	10787,0%	0,9%	99,1%	0,00%	100,0%
0,02	19,5%	53,6%	46,4%	0,00%	100,00%	0,02	910,0%	51,7%	48,3%	3,11%	96,9%
0,05	19,4%	54,2%	45,8%	0,03%	99,97%	0,05	327,7%	67,7%	32,3%	6,53%	93,5%
0,1	19,1%	55,1%	44,9%	0,10%	99,90%	0,10	134,7%	78,1%	21,9%	11,27%	88,7%
0,2	18,7%	57,0%	43,0%	0,41%	99,59%	0,20	50,1%	86,3%	13,7%	18,71%	81,3%
0,3	18,2%	58,9%	41,1%	0,90%	99,10%	0,30	26,8%	89,9%	10,1%	24,27%	75,7%
0,5	17,2%	62,4%	37,6%	2,42%	97,58%	0,50	11,6%	93,5%	6,5%	32,85%	67,2%
1	14,4%	70,3%	29,7%	8,78%	91,22%	1,00	3,4%	96,6%	3,4%	47,24%	52,8%
1,2	13,4%	73,1%	26,9%	12,06%	87,94%	1,20	2,4%	97,2%	2,8%	51,12%	48,9%
2	9,4%	82,1%	17,9%	27,62%	72,38%	2,00	0,9%	98,4%	1,6%	62,78%	37,2%
2,5	7,4%	86,3%	13,7%	37,73%	62,27%	2,50	0,6%	98,8%	1,2%	67,79%	32,2%
3	5,7%	89,6%	10,4%	47,38%	52,62%	3,00	0,4%	99,0%	1,0%	71,85%	28,2%
3,5	4,4%	92,1%	7,9%	56,18%	43,82%	3,50	0,3%	99,2%	0,8%	75,24%	24,8%
4	3,4%	94,1%	5,9%	63,95%	36,05%	4,00	0,2%	99,3%	0,7%	78,13%	21,9%
4,5	2,6%	95,5%	4,5%	70,65%	29,35%	4,50	0,2%	99,4%	0,6%	80,65%	19,4%
5	1,9%	96,6%	3,4%	76,32%	23,68%	5,00	0,1%	99,5%	0,5%	82,86%	17,1%
5,5	1,5%	97,5%	2,5%	81,05%	18,95%	5,50	0,1%	99,5%	0,5%	84,82%	15,2%
6	1,1%	98,1%	1,9%	84,95%	15,05%	6,00	0,1%	99,6%	0,4%	86,59%	13,4%
6,5	0,8%	98,6%	1,4%	88,14%	11,86%	6,50	0,1%	99,6%	0,4%	88,18%	11,8%
7	0,6%	98,9%	1,1%	90,72%	9,28%	7,00	0,1%	99,7%	0,3%	89,63%	10,4%
7,5	0,5%	99,2%	0,8%	92,80%	7,20%	7,50	0,1%	99,7%	0,3%	90,95%	9,0%
8	0,3%	99,4%	0,6%	94,46%	5,54%	8,00	0,0%	99,7%	0,3%	92,17%	7,8%
8,5	0,3%	99,6%	0,4%	95,79%	4,21%	8,50	0,0%	99,7%	0,3%	93,30%	6,7%
9	0,2%	99,7%	0,3%	96,84%	3,16%	9,00	0,0%	99,8%	0,2%	94,34%	5,7%
9,5	0,1%	99,8%	0,2%	97,67%	2,33%	9,50	0,0%	99,8%	0,2%	95,32%	4,7%
10	0,1%	99,8%	0,2%	98,33%	1,67%	10,00	0,0%	99,8%	0,2%	96,22%	3,8%
10,5	0,1%	99,9%	0,1%	98,84%	1,16%	10,50	0,0%	99,8%	0,2%	97,07%	2,9%
11	0,1%	99,9%	0,1%	99,25%	0,75%	11,00	0,0%	99,8%	0,2%	97,87%	2,1%
11,5	0,0%	99,9%	0,1%	99,56%	0,44%	11,50	0,0%	99,8%	0,2%	98,62%	1,4%
12	0,0%	99,9%	0,1%	99,81%	0,19%	12,00	0,0%	99,8%	0,2%	99,33%	0,7%

3. Minimum flow measurement and measurement uncertainty

The start-up flow rate (Qstart) of a meter is highly significant for the quantification of benefits in post-meter leakage detection. The reference standards for some measurement technologies define the maximum Qstart value (Table 2). Indeed, the measurement technologies currently used for most domestic users (Qmax = 6 m^3/h) allow the detection of flows below the metrological Qstart defined by the standards (Table 2).

For meters with a mechanical measuring element, the Qstart is defined by the solution adopted by the different manufacturers and cannot be changed, but, for example, for Pietro Fiorentini SpA's meters, the actual start-up flow rate (Q'start), i.e. the flow rate at which the meter begins to measure, can be around 3 dm^3/h, which is lower than the metrological Qstart. Measurement uncertainty, resolution and repeatability at Q'start are currently not characterised by all manufacturers. In meters with mechanical measurement technology, regardless of the measurement error, the gas metered with Q'start flow rate is still metered and therefore paid for by the user. In meters with a mechanical measuring element, the Q'start value has no influence on smart meter battery consumption.

In meters with static measurement technology (ultrasonic and mass), Qstart is defined by the firmware and Q' start depends on the design solution adopted: both Qstart and Q'start are a compromise between the need not to count in the absence of flow and to reduce the energy expenditure of the battery that the measurement module is energetically supported by. For some solutions, such as those of Pietro Fiorentini, it is possible to reduce the Q'start by up to 5 dm3/h without significant compromise. Tests carried out by Pietro Fiorentini with its meters using ultrasonic measurement technology have shown the technology's ability to detect gas flows of more than 1-1.2 dm^3/h even though, for energy reasons, this capacity cannot be maintained constantly over time.

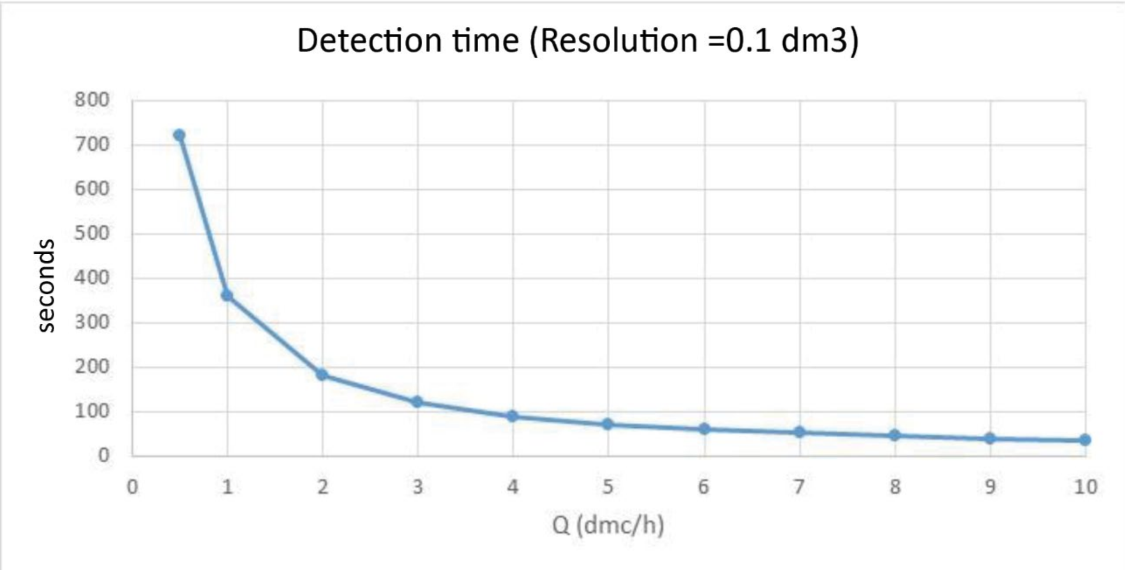
The error with which the meter must be able to measure gas flows that are less than its minimum flow rate is not defined for all measurement technologies. The measurement uncertainty and repeatability for flow rates between Q'start and Qstart is generally not declared by the manufacturer. It can be assumed that for all measurement technologies, including mechanical measurement, the measurement error remains constant between Q'start and Qmin and equal to the stated error for Qstart (Table 2). Generally, meters at low flow rates tend to measure by underestimating the flow (negative error). Negative error is not decisive for cost-benefit analysis as it tends to underestimate the extent of the leak but can nevertheless contribute to false negatives. Conversely, the positive error, although more unlikely, contributes to overestimating the extent of the leak and may lead to false positives.

Table 2 - Start-up flow rate for the various measurement technologies

Measurement technology	*Reference Standards*	*Max Qstart (dm3/h)*	*Error at Qstart*
Mechanical measurement (diaphragm)	EN 1359	3 @Qmax =2.5 m3/h 5 @Qmax =4 m3/h 5 @Qmax =6 m3/h 8 @ Qmax=10 m3/h	Not defined
Static measurement (ultrasonic)	EN14236	0.25 * Qmin	- 50% + 10.5%
Static measurement (mass)	EN17526	4 @ Qmax=2.5 m3/h 6.25 @Qmax =4 m3/h 10 @Qmax =6 m3/h 15 @Qmax =10 m3/h	- 50% + 10.5%

Flow measurement in volumetric meters (diaphragm, rotary pistons) is achieved by integration of the measured volumes. The integration period (Ti), to avoid false negatives, must be as small as possible in accordance with the formula [F1] that relates the minimum leakage flow to be detected and the resolution of the meter. For example, with a meter resolution of no more than 0.1 dm^3, an integration time of 6 minutes is sufficient to be able to measure leakage flows of more than 1 dm^3/h; whereas for measuring systems with a resolution of 10 dm^3/h, 200 minutes would be required to detect a leakage of 3 dm^3/h, and during this time the user would not have to consume any gas to avoid false negatives.

$$Ti(minutes) = \frac{Resolution\ (dmc)\times 60}{q\_leak(dmc/h)} \qquad [F1]$$



4. Cost and benefit analysis

4.1 Foreword

The amount of CO2 equivalent emissions related to a fugitive emission of q_{leak} flow rate is given by:

$$Eeq = K \times q_{leak} \times t_p \qquad [F\ 2]$$

K being the factor that takes into account the percentage of methane present in the natural gas, the density at reference thermodynamic conditions and the equivalence between one tonne of methane and one tonne of CO_2, which in this context, as mentioned above, is conservatively estimated to be 2817 while 'tp' is the persistence time of the leakage. Obviously, by reducing 'tp', Eeq is reduced proportionally.

The case analysed involves a system capable of recognising, accounting for and alerting the distributor and the user of a leak occurring in the systems downstream of the meter, so that action can be taken as quickly as possible to eliminate it.

To recognise and account for this type of leak, the solution proposed by Pietro Fiorentini employs smart meters. For this purpose, smart meters must be equipped with firmware capable of detecting and measuring a possible 'background flow', i.e. a flow that is maintained during the day: a flow other than zero (or above a threshold), under normal consumption conditions and in most cases, should not persist for an entire day. However, there are cases of abnormal consumption that could be falsely interpreted by the system as leakage ('false positives') or leakage conditions that are not detected ('false negatives')18. The cost-benefit analysis takes into account percentages of both false positives and false negatives; the amount of false positives and/or negatives, if not limited, have a negative impact on profits.

In order to limit false positives and negatives, the use case investigated for the cost-benefit analysis involves the use of a software application (AMC) that performs the function of an analysis centre for the data generated by the smart meter, which is sent to the AMC from the central data acquisition system (SAC) currently present[19]. It is up to the meter to detect and measure abnormal flows, and up to AMC to recognise whether these flows are leaks or represent a 'false positive', also using 'analytics' that take into account the historical consumption conditions of each system, or to suggest, when possible, appropriate smart meter reconfigurations to limit the occurrence of 'false negatives'. The complexity (and thus the cost) of AMC depends on the efficiency one wants to sustain with the solution.

Since emission savings due to leakage are also achieved by reducing the time -tp- of leakage persistence, it is necessary for AMC to recognise the leakage condition as soon as possible. To better justify the investment in the development and management of the AMC,

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[17] For the purpose of greenhouse gas emissions 1 tonne Ch4 is equivalent to 28 tonnes CO_2, over a 100-year period

[18] A 'false positive' is e.g. caused by a constant consumption condition due to the heating system failing to bring the room temperature to the set value; a 'false negative' is generally related to a high Q'start value and/or a high integration period for the flow rate calculation.

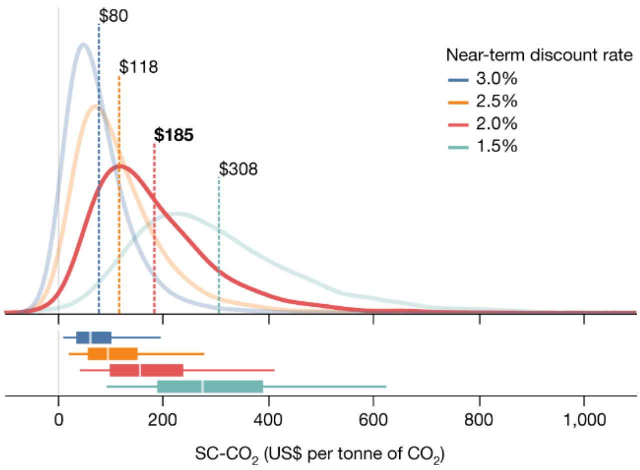
[19] The SAC is the centre responsible for acquiring data from smart meters

it could be used to manage other events that are either generated by the meters or processed from data received from them[20].

4.2 Social Cost of Carbon Emissions (SCC)

The social cost of carbon (SCC) corresponds to the economic value of the damage caused by adverse climate events resulting from the release of one tonne of CO_2 or another climate-altering gas such as methane gas into the atmosphere. The valuation of SCC is very complex and lends itself to various often conflicting estimates: mathematical models are generally used to link the social, economic and physical characteristics of the scenario under observation into an overall picture. These models, called the integrated approach models, integrate four different types of information: socio-economic scenarios (e.g. what the population will be in a certain year, how much the economy will grow and how much carbon emissions it will entail), climate scenarios (how fast sea levels and temperatures will rise, for example), costs and benefits (how climate change will affect the ability of economic systems to produce well-being) and, last but not least, the *discount rate*. The first three are highly variable and therefore difficult to predict: hypotheses rather than forecasts are used to determine them. The discount rate, on the other hand, is to some extent controllable and has an *ethical* value. In fact, it indicates how much society is willing to give up its current benefits in favour of those of future generations. The discount rate is a key parameter in determining SCC, if one considers that a tonne of CO2 emitted today produces damage for many years to come. Reducing emissions avoids damage in the future but requires paying its cost today. In other words, a high discount rate (i.e. a preference for the present) leads to spending less money on the climate today, but passes on the higher costs of this policy to posterity. Conversely, a low discount rate indicates a willingness to spend more today to protect future generations.

Figure 4 - SCC as a function of applied discount rate (Source: Nature.com)



[20] For example: abnormal consumption conditions, inadequate supply quality, detection of seismic events or gas leaks from sensors, etc.

Below are the SCC estimates made by IWG[21] for the period 2020 - 2050

Table 3 - SCC according to IWG report 2021

SCC	**Average estimate at 5% discount rate**	**Average estimate at 3% discount rate**	**Average estimate at 2.5% discount rate**	**High Impact Estimate (95thpercentile estimate at 3%discount rate)**
2020	$14	$51	$76	$152
2025	$17	$56	$83	$169
2030	$19	$62	$89	$187
2035	$22	$67	$96	$206
2040	$25	$73	$103	$225
2045	$28	$79	$110	$242
2050	$31	$85	$116	$260

A report by the National Academies of Sciences, Engineering, and Medicine (NASEM) in the US recently pointed out that SC-CO_2 estimates no longer reflect older research. The report provided several recommendations to improve the scientific basis and characterisation of the uncertainty of SC-CO_2 estimates. In response to NASEM's recommendations, an authoritative study[22] was drafted, which adjusts the SCC estimates to $119 per tonne of CO_2 at a short-term, low-risk discount rate of 2.5%. This SCC value, equivalent to **107.30 Euro** (1$=0.909€), will be used as a reference for the analysis.

[21] IWG (Interagency Working Group); estimates provided in the Technical Support Document
[22] https://www.nature.com/articles/s41586-022-05224-9

4.3 Costs and benefits

The cost of a leak is the sum of the cost of the raw material (energy) that is lost and the social cost of carbon (SCC). Table 4 shows the costs incurred by the user, as part of the community, and associated with leaks of different magnitudes[23].

Table 4 - User costs

Leakage Flow (dmc/h)	Yearly Leakage (mc/y)	Yearly Leakage (kg/y)	Yearly Average Gas Cost	Yearly Emissions (tCO2eq)	Yearly SCC	Yearly Total Cost
1	8,8	5,6	7,88 €	0,148	15,89 €	23,77 €
1,2	10,5	6,7	9,46 €	0,178	19,06 €	28,52 €
2	17,5	11,2	15,77 €	0,296	31,77 €	47,54 €
3	26,3	16,8	23,65 €	0,444	47,66 €	71,31 €
4	35,0	22,4	31,54 €	0,592	63,54 €	95,08 €
5	43,8	28,0	39,42 €	0,740	79,43 €	118,85 €
6	52,6	33,6	47,30 €	0,888	95,31 €	142,61 €
7	61,3	39,2	55,19 €	1,036	111,20 €	166,38 €
8	70,1	44,9	63,07 €	1,184	127,08 €	190,15 €
9	78,8	50,5	70,96 €	1,332	142,97 €	213,92 €
10	87,6	56,1	78,84 €	1,480	158,85 €	237,69 €
20	175,2	112,1	157,7	3,0	317,70 €	475,38 €
50	438,0	280,3	394,2	7,4	794,25 €	1.188,45 €
1%	0,088	0,056	0,08 €	0,001	0,16 €	0,24 €

The values given in Table 4 suggest the following considerations:

- The unit percentage error (1%) in the measurement of a leak is worth about 56 grams of gas per year and a total cost of almost 24 €cent
- Flows of less than 10 dm^3/h are generally not attributable to normal domestic gas use[24] and are almost certainly due to leaks. With the assumed probability distributions, we have the probability that almost all users (99.8%) have leaks of no more than 10 dm^3/h (Table 1)
- Flows of less than 3 dm^3/h, as a result of the above, are hardly detectable with currently used metering technologies; gas lost after the meter when the flow is less than Q'start is not accounted for by the user's meter and remains charged to the community as unaccounted for gas (UAFG).
- To be able to measure flows (leaks) below 3 dm^3/h as required by metrology, the development of new measurement solutions is necessary (e.g. the new ultrasonic measurement technology that will be dealt with in the CB hypothesis, capable of measuring flows of 1-1.1 dm^3/h).

[23] Average CNG cost to user 90€cent/m3; SCC =107.30€

[24] The pilot flame of a boiler, which can remain permanently lit, consumes 10 to 40 litres/h, while the smallest burner on the hob consumes about 60 dm^3/h. Some condensing boilers in certain types of use may maintain a constant consumption of 0.1m^3/h

- Flows of less than 1dm^3/h are difficult to measure. These flows, which are certainly due to leaks when detected, would be practically difficult to eliminate. Dispersed flows of this magnitude hardly constitute a danger and are tolerated by the standard (UNI 11137). Moreover, as is evident from Table 4, there is no interest for the user to bear the (much higher) costs of repairing their own system if it is affected by fugitives of this magnitude. For these reasons, the flow rate of 1 dm^3/h will be the minimum leakage value considered in the CBA. However, a leakage flow of about 1 dm^3/h that is not eliminated generates about 1.5 tCO_2eq for each user in 10 years and, according to the probability distributions considered, there could be from 3% to 14% (> 700,000) of users who have leaks of this magnitude.
- For safety aspects, permanent gas flows of up to 5 dm^3/h, almost certainly attributable to leaks, can be managed without high criticality; gas flows of more than 5 dm^3/h and up to 10 dm^3/h attributable to leaks must be managed with greater care and rapid intervention times; gas flows of more than 10 dm^3/h attributable to leaks must be managed with high priority (alarms) as they could compromise the safety of the installations as well as represent a significant cost for the user and the community[25].
- As far as the economics of the 'tp' are concerned, as Table 4 shows, each day of delay in eliminating the leak has a total cost of 6.5 €cent/dm^3; thus, for example, a leakage of 7 dm^3/h entails a total cost of more than 45 €cent for each day of persistence of the leak (comparable to the cost of one cubic metre of gas).
- Each cubic metre of gas not emitted in a year generates a saving of €2.70 considering both the raw material and the SCC [26].

For the analysis of incurred costs and expected benefits, additional costs[27] of Table 5 and Table 6 are taken into account, estimated by Pietro Fiorentini, related to the implementation and management of the new leakage interception function with the support of the smart meter. For CBA, additional benefits, estimated by Pietro Fiorentini, not generated by the current meters, are also taken into account in Table 7 and resulting from the implementation of the function.

[25] Respectively higher than 78 € and 158 € per year according to Tabella 4

[26] Raw material cost of 64€cent and SCC=107.3 €/tonCO2eq

[27] The extra costs and extra-profits taken into account by the CBA are additional to those known to arise from the use of smart meters

Table 5 - Additional costs for the distributor

	Cost item	Cost type	Attributable to
Cd-1	New SAC[28] software integrations	CAPEX	DisCo
Cd-2	Development and integration of the AMC SW[28]	CAPEX	DisCo
Cd-3	AMC software maintenance[28]	OPEX	DisCo
Cd-4	False positive management[29]	OPEX	DisCo
Cd-5	Management of the AMC centre[28]	OPEX	DisCo
Cd-6	Smart Meter additional cost	CAPEX	DisCo
Cd-7	Cost of intervention to verify a leak report[29]	OPEX	DisCo
Cd-8	Cost for (early) replacement of an existing meter[29]	OPEX	DisCo
Cd-9	Existing smart meter firmware upgrade cost[28]	OPEX	DisCo
Cd-10	Discount rate[30]		DisCo

Table 6 - Additional costs for the manufacturer

	Cost item	Cost type	Attributable to
Cc-1	Smart meter firmware developments	CAPEX	Manufacturer
Cc-2	Firmware maintenance	OPEX	Manufacturer
Cc-3	Smart meter hardware developments	CAPEX	Manufacturer
Cc-4	Certifications and approvals	CAPEX	Manufacturer
Cc-5	Production process adaptation	CAPEX	Manufacturer

Table 7- Benefits

	Benefit item	Benefit type	Attributable to
B1	Methane (energy) saved	Recurring	Community
B2	SCC avoided	Recurring	Community
B3	Gas turnover	Recurring	Seller
B4	UAFG reduction	Recurring	Distributor

In the hypothesised use case, cost item Cd-7 considers the costs that the distributor would have to incur as a result of a leak in order to contact the user and to carry out an inspection of the system before proceeding to a possible suspension of the supply. These costs are, however, incurred in the case of 'false positives', i.e. alleged leaks identified by AMC that are found to be non-existent upon verification.

Cd-8 is the cost to be borne by the Distributor in the case (which will be analysed) where a meter in use is to be replaced before the end of its regulatory life.

[28] Value estimated by Pietro Fiorentini considering similar applications
[29] These costs were valued as an average of values provided by two distributors
[30] Referred to the value set by the ECB (European Central Bank) in September 2023

Cd-9 is the cost that the Distributor will be required to sustain in the case (which will be analysed) where they want to upgrade the firmware of a smart meter in use so that it can provide the post-meter leak reduction function.

Cc-x are the average costs that manufacturers have to sustain for design, development of both hardware and firmware, certifications (ATEX, MID, functional, etc.) and adaptation of the production process. These costs determine the extra price to be added to the current average price of the smart meter without the considered function.
The analysis uses estimates made by Pietro Fiorentini with their own products

4.4 Reference scenario and hypotheses

For the cost-benefit analysis, three hypotheses are considered articulated around a reference scenario whose metrics are described in Table 8.

The reference scenario considers a distributor distributing gas to 126,903 users[31] who use gas for domestic use equipped with meters up to gauge G6 (Qmax=10 m^3/h). The results of the analysis, under different hypotheses, carried out for the reference distributor can be traced back to the entire national context by considering a multiplication factor of 186 equal to the number of distributors operating in Italy[32].

The reference scenario assumes that only 80% of the intercepted post-meter leakages can be resolved[33] and that there is a 10% occurrence of 'false positives': both values are however subject to sensitivity analysis.

The reference scenario assumes 5 years as the time needed to equip a grid with new smart meters with a constant progression[34] and without considering the possible reuse of meters that may have been decommissioned. The benefits expected from the implementation of this feature, as attested by the CBA, increase with the reduction of the time taken for compliance since the effects of emission reduction begin earlier and persist for a longer time.

The reference scenario assumes an observation period (over which costs and benefits are updated) of 15 years, which takes into account the useful life of the meter; over the same period, the total emissions due to leaks are also accounted for, assuming that a leakage occurring in one year, if not resolved, continues to generate emissions with a constant flow rate until the end of the period[35]. The calculation of avoided leaks starts from the year following the year of installation. A system in which a leak has been detected and which is resolved is no longer affected by leaks at least until the end of the observation period. A system in which there is no leak in the first year is considered to be leak-free for all subsequent years. False positives are estimated in the reference scenario to be 5% of the smart meter inventory that has been installed or adjusted and may occur every year of the

[31] Value obtained by dividing the total number of users (23,604,000) by the number of distributors (186) rounded to obtain a nil remainder
[32] Data elaborated from "Annual Report -Status of Services 2022" - ARERA
[33] It is assumed that 20 % of intercepted leaks are not resolved due to user unavailability or meter inaccessibility.
[34] In the case of the country, approximately 4,720,000 smart meters would be installed each year, a quantity that is considered congruous both in terms of meter availability and installation effort
[35] In reality, it is very likely that the flow of a leak tends to increase over time

observation period. 'False negatives', i.e. undetected leaks, are considered in the context of undetected leak rates[36].

Table 8 - Reference scenario

Metrics	Acronym	Value	UoM	Sourcew
Social Cost of Carbon	scc	107.3	€/tonne	IWG (Interagency Working Group) Technical Support Document
Average cost of gas (raw material)	Cgas	0.64	€/m3	ARERA - Average over the last 2 years
Average cost of gas (for the user)	Cugas	0.9	€/m3	ARERA - Average over the last 2 years
Post meter natural gas fugitive leaks	Leak	42.4	millions me	ISPRA - report 383-2023
Domestic post-meter methane fugitive leaks (G2.5-G6)	Leak_dom	41.52	millions me	*[estimate by calculation]*
User totals	PdR	24.103	millions	ARERA - Annual report 2022
Home user totals (G2.5-G6)	PdR_dom	23.604	millions	ARERA - Annual report 2022
Home user totals (G2.5-G6) with SmartMeter	PdR	19.120	millions	ARERA - Annual report 2022
Number of distributors (as at 2022)	DisCo	186		ARERA - Annual report 2022
Observation period	DP	15	years	*equal to the lifetime of the smart meter*
Meter activation period	Pa	5	years	*hypothesis - sensitivity analysis*
Probability distribution		Distrib. GUMBEL		
Average leak of users		0.20	dm^3/h	*calculation*
Standard deviation		2.20	dm^3/h	*calculation-sensitivity analysis*
Intercepted and fixed leaks	Elr	80%		*hypothesis - sensitivity analysis*
Intercepted leaks but 'false positives'	Fp	5%		*hypothesis - sensitivity analysis*
Standard cost of smart meters	Cstd	150.00 €		*Arera-Of 737-22 (122€ in 2024)*
Cost of a system leakage check	Cvi	35	€	Average of values provided by 2 distributors (minimum lh)
Equivalence coefficient m^3 CH_4/tonCO_2	Kch4/co2	0.01689996		ISPRA - report 386-2023 (ltonCH4=28tonC02eq)
Discount rate	Ts	4.50%		ECB as at Sept. 2023

The following hypotheses that will be analysed are based on Pietro Fiorentini's meter technology:

The AI or 'AS IS' hypothesis - this hypothesis envisages the use of current smart meters (both mechanical and static measurement technology) without any hardware modifications but equipped with appropriate firmware capable of detecting and measuring leakage flows. The AI Hypothesis is divided into two sub-hypotheses AI and AI-2; AI considers both measurement technologies that have a meter Q'start of 3dm^3/h ; AI-2 on the other hand only considers meters with static measurement technology, for which Pietro Fiorentini assumes reducing the Q'start to at least 1.2 dm^3/h but only when it is necessary to verify the existence of a possible permanent leakage with flow below Q'start.

CB or 'COULD BE' hypothesis - the hypothesis evaluates the costs and benefits of the solution involving the development of a new (static) measurement technology capable of permanently measuring gas flows of not less than 1 dm^3/h.

The different hypotheses provide for costs for investments and benefits for intercepted leaks of different magnitudes and consider the reference scenario, with the variants that will be detailed.

For the AI hypothesis, the **ROI** sensitivity analyses will be carried out considering the most significant variables; for the other hypotheses, it is assumed that the sensitivity analysis will provide equivalent results. The significance of a variable is determined by two indicators: 'vi' and 'r'. Indicator 'vi' expresses the difference between the maximum and minimum value of the ROI when the variable assumes values in the range of interest; indicator 'r' expresses

[36] In the AI Hypothesis where intercepted and resolved leaks are 22%, this percentage is net of false negatives, so false negatives are part of the 78% of un-intercepted leaks

the ratio of the number of cases in which ROI >0 to the number of cases considered. Higher values of 'vi' or lower values of 'r' identify a relevant variable for the calculation of ROI.

If deemed significant, the hypotheses are evaluated according to the two probability distributions considered (Gumbel and Lognormal)

4.4.1 AI Hypothesis ('As Is')

The cost-benefit analysis conducted with reference scenario parameters in the AI Hypothesis use case generates the following results:

Table 9 - AI hypothesis results

Hypothesis AI - (single distribution network scenario)	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 1.180.625	€ -	€ (1.180.625)	€ 9	€ -
GasCo	€ -	€ -	€ -	€ -	€ -
Community	€ -	€ 2.549.522	€ 2.549.522	€ -	€ 20
Total	**€ 1.180.625**	**€ 2.549.522**	**€ 1.368.898**	**€ 9**	**€ 20**

R O I	**1,15**			
R O Ics	**6,8%**			
Eco_Cost (€/tCO2eq)	**61,95 €**			
%AE	**31,6%**	***Avoided Emissions (tCO2eq)***	**19.058**	

Cost item Cc-1 related to the realisation of the firmware needed for this hypothesis was estimated by Pietro Fiorentini to be around 200 K€

21% of the costs incurred by DSO are capital costs (CAPEX), of which 17% are attributable to the preparation of the AMC (Cd-2); 40% of the operating costs (OPEX) are necessary for the maintenance and operation of the AMC; 50% are operating costs to support the audits of systems where leaks have been detected, of which 16% are operating costs attributable to the checks of false positives.

In terms of community benefits over the observation period, 20% can be attributed to methane saved and the remaining 80% to SCC avoided.

ROI stands at 115% and the ROI$_{CS}$ at 7%, the Ecological Cost is 62 € per tonCO2eq. The efficacy of the solution (%AE) is over 31%

With the same hypotheses as in the reference scenario but considering a Lognormal probability distribution (with equal mean and standard deviation), the analysis yields the following results:

Hypothesis AI - (single distribution network scenario)	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 619.359	€ -	€ (619.359)	€ 5	€ -
GasCo	€ -	€ -	€ -	€ -	€ -
Community	€ -	€ 1.363.978	€ 1.363.978	€ -	€ 11
Total	**€ 619.359**	**€ 1.363.978**	**€ 744.619**	**€ 5**	**€ 11**

R O I	**1,20**			
R O Ics	**3,8%**			
Eco_Cost (€/tCO2eq)	**60,75 €**			
%AE	**16,9%**	***Avoided Emissions (tCO2eq)***	**10.196**	

For the financial aspect (ROI and ECO_Cost), the results obtained with the two distributions are almost equivalent, but the emissions intercepted and eliminated, for the lognormal distribution, would be about half of those assumed with the Gumbel distribution. The lognormal function tends to emphasise small leaks and would result (Table 1) in only 28% of the leaks that can be intercepted if the Qstart is 3 dm^3/h (for Gumbel it would be 52%). On the other hand, intercepting fewer leaks means savings for the distributor since it does not have to bear the costs of checking and intercepting the supply, so the ROI tends to increase.

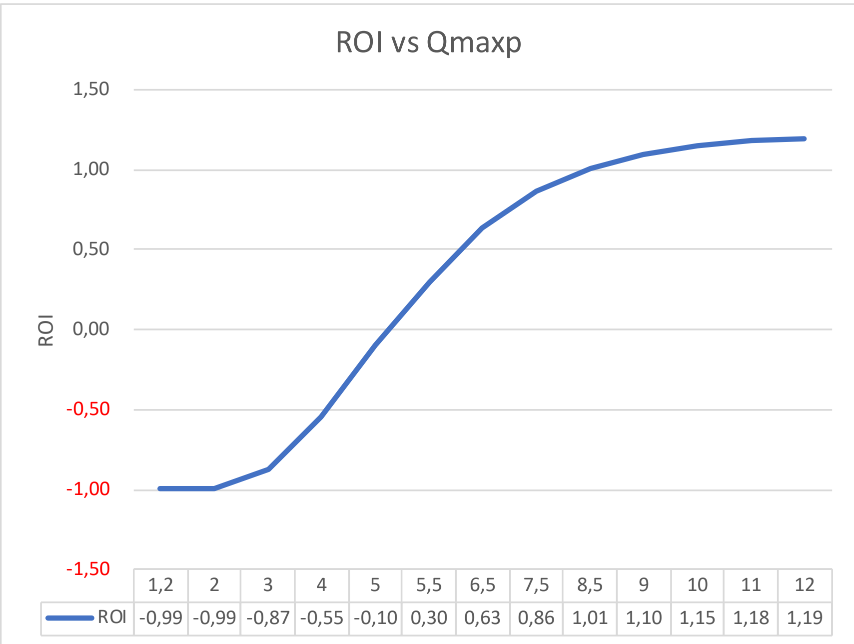
The most significant variables for ROI and therefore to be considered for the sensitivity analysis are: **the maximum probable leakage flow** (i.e. the standard deviation of the probability distribution), the **smart meter's ability to detect leaks** (i.e. the Q'start), the **assessment of the overall post-meter gas emissions**, the **efficacy in resolving intercepted leaks, the cost of setting up and running the AMC centre**, the **ability to discriminate 'false positives', the size of the distribution grid** (i.e. the number of grid users) , the assessment of the **social cost of carbon**.

4.4.1.1 AI Hypothesis - Maximum probable leak flow

The results in the AI hypothesis shown in Table 9 assume a maximum probable leakage flow of 10 dm^3/h, i.e. it is assumed that more than 99% of the leaks occur with a flow of less than 10 dm^3/h[37]. The value of the maximum leak flow, given the same mean value, is a function of the standard deviation of the probability function. If greater maximum probable leak flows are allowed for, the ROI tends to improve (Chart 1). If, on the contrary, it is assumed that the average maximum flow is less than 10 dm^3/h the ROI tends to worsen as the smart meter of the AI hypothesis intercepts fewer leaks. With a most probable maximum leak of about 6 dm^3/h, AI hypothesis reaches the break-even point. Therefore, if it turns out that most post-meter leaks occur with flows that are unlikely to exceed 5 dm^3/h, the smart meter solution considered in the AI hypothesis is inefficient.

Chart 1 - ROI as a function of the most probable maximum leak

Hypotesis AI - ***Distrib. GUMBEL - μ = 0,2***		
Qmaxp (dmc/h)	***StdDev (dmc/h)***	**ROI**
1,2	0,2	-0,99
2	0,4	-0,99
3	0,6	-0,87
4	0,8	-0,55
5	1	-0,10
5,5	1,2	0,30
6,5	1,4	0,63
7,5	1,6	0,86
8,5	1,8	1,01
9	2	1,10
10	2,2	1,15
11	2,4	1,18
12	2,6	1,19



[37] This leads to the assumption of the standard deviation (σ) of 2.2 dm^3/h

4.4.1.2 AI hypothesis - Smart meter capability to detect leaks

The smart meter's capability to detect post-meter leakage depends exponentially on the measuring element's capability to measure small flow rates, i.e. its Q'start. The sensitivity analysis of ROI to Q'start is depicted in Chart 2.

The analysis shows that smart meters with static metering technology that measure from the maximum Qstart allowed by the product standard (10 dm^3/h), realise a certainly negative ROI (-0.85). Mechanical measurement technology already with the metrological Qstart of 5 dm^3/h results in an ROI of 50%. Since both of Pietro Fiorentini's measurement technologies are capable of measuring minimum flow rates of around 3 dm^3/h (Q'start), even under the conservative hypotheses of the scenario, both result in an ROI of around 1.15.

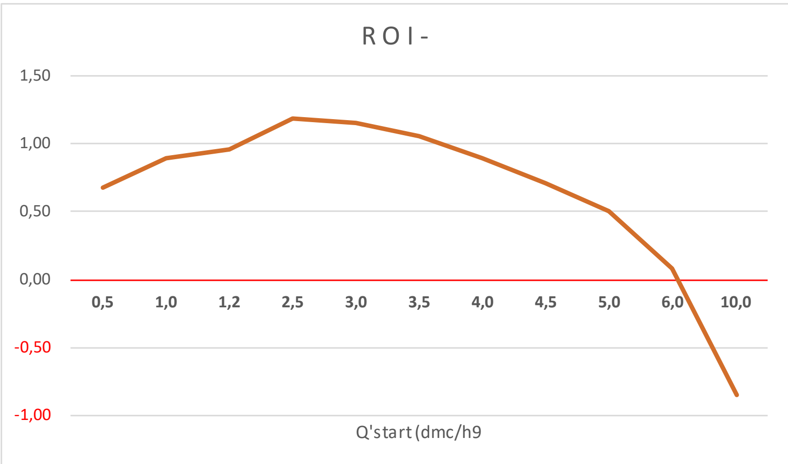
In the AI hypothesis, with the reference scenario, in the vicinity of a Q'start = 2.5 dm^3/h the maximum ROI (and minimum Eco_Cost) is obtained for the AI hypothesis: for values lower than 2.5 dm^3/h the number of users affected by leakage increases and thus the costs incurred for its verification and elimination increase; for values higher than 2.5 dm^3/h the intercepted emissions decrease until the ROI reaches negative values. The break-even point (ROI=0) is obtained, instead, with a Qstart close to 6 dm^3/h.

The sensitivity analysis would indicate that from an economic point of view (ROI and Eco_Cost) there is no advantage in intercepting leaks with a flow below 2.5-3 dm^3/h. However, as is evident from **Error! Reference source not found.**, reducing the Q'start from 3 dm^3/h to 1 dm^3/h would allow more than 38% more leaks to be intercepted (25% according to the Lognormal distribution)

Chart 2 - ROI as a function of the measurable minimum leak

Hypothesis AI - R O I

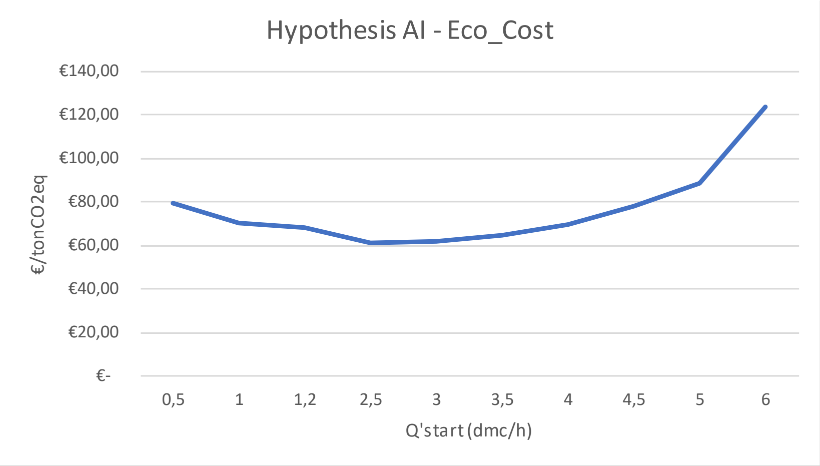
Q'start (dmc/h)	
0,5	0,68
1,0	0,89
1,2	0,96
2,5	1,19
3,0	1,15
3,5	1,06
4,0	0,90
4,5	0,71
5,0	0,50
6,0	0,08
10,0	-0,85



Hypothesis AI - Eco_Cost

Q'start (dmc/h)	
0,5	79,32
1,0	70,58
1,2	68,01
2,5	61,00
3,0	61,95
3,5	64,90
4,0	70,07
4,5	77,82
5,0	88,72
6,0	123,50
10,0	942,61

vi = 9,5- r = 1



4.4.1.3 AI Hypothesis - Total methane emissions

The reference scenario estimates post-meter natural gas leakage with emission factor 36kg CH_4 per TeraJoule of energy distributed to households and taken from the German reality of the 1990s. In 2021, the natural gas leaks estimated with this factor were 42.4 Mm^3 or approximately equal to 25.6 kt of CH_4. Estimating post-meter methane emissions as a function of distributed energy may, however, be unrealistic as it is conceivable that these emissions are influenced more by the amount of users than by the amount of energy distributed. Comparing the emission factor estimate for Italy (1.07 kg-CH_4/user) with the one provided by the IPCC and EPA for the USA (pf 2 – Types of leaks) suggests an underestimation of post-meter emissions. The total quantity of emissions determines the average leakage as well as the standard deviation at the same maximum leakage flow considered (Appendix A).

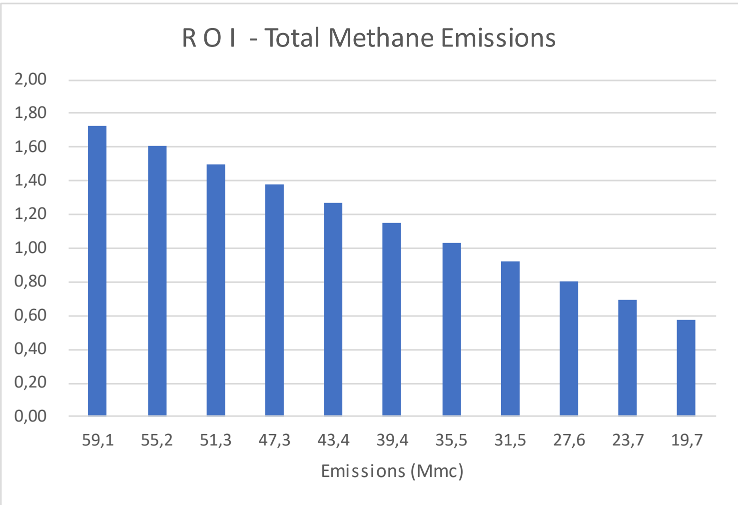
The sensitivity analysis conducted on the estimated total quantities of post-metered methane emissions provided the results of Chart 3. The analysis shows that the post-meter emissions estimate is not decisive for the ROI (vi=1.15; r=1), which remains significant (> 58%) even if the total emissions estimate were to fall short or exceed the reference scenario estimate by 50%.

Chart 2- ROI as a function of total emissions

Hypothesis AI - R O I

Total Methane Emissions (mc)		
59.148.000	1,73	150%
55.204.800	1,61	
51.261.600	1,50	
47.318.400	1,38	
43.375.200	1,27	
39.432.000	1,15	
35.488.800	1,04	
31.545.600	0,92	
27.602.400	0,81	
23.659.200	0,69	
19.716.000	0,58	50%

vi = 1,15- r = 1



4.4.1.4 AI Hypothesis - Intercepted leak resolution efficacy

When methane leaks are intercepted, they must be eliminated or reduced to achieve emission reduction. In order to eliminate the leak, the safety criterion can be applied, and the supply can be suspended to those plants that have leakages exceeding 1 dm^3/h. However, not all intercepted leaks, even if they are above the regulatory acceptability limit, can be resolved mainly due to the distributor's inability or difficulty in gaining access to the plant.

The smart meters installed in Italy in the type of user being considered (Qmax < 10m^3/h) are equipped with a valve that would allow the gas supply to be intercepted remotely to users affected by leaks but not available for their elimination. However, in a worst-case scenario, this solution, although technically feasible, was not considered in the CBA. The reference scenario, on the contrary, assumes that it is not possible to eliminate leaks in 20% of the systems in which they have been identified, for various reasons.

The sensitivity analysis showed (Chart 4) how the ROI, in the AI hypothesis, remains positive as long as at least 40% of the intercepted leaks are resolved. The Eco_Cost could be reduced to 55 €/tonCO_2eq if 90% of the leaks intercepted by smart meters could be eliminated.

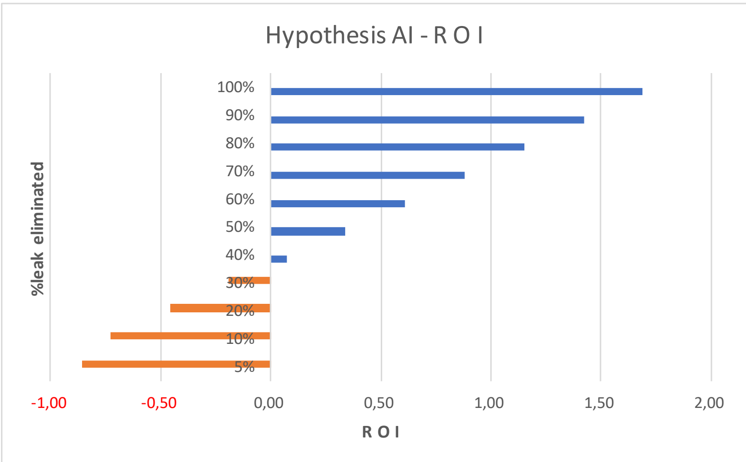
Chart 3 - ROI and Eco_Cost related to the number of resolved leaks

Hypothesis AI - R O I

1,15 €

%leak eliminated		
	5%	-0,86
	10%	-0,73
	20%	-0,46
	30%	-0,19
	40%	0,07
	50%	0,34
	60%	0,61
	70%	0,88
	80%	1,15
	90%	1,42
	100%	1,69

vi = 2,55- r = 0,63

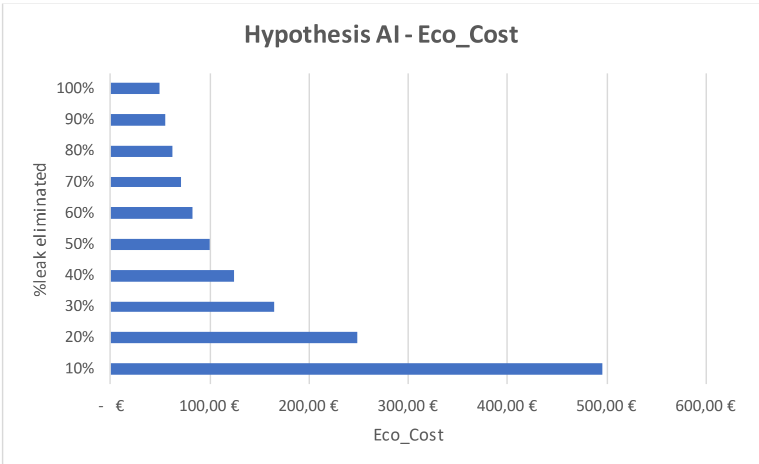


Hypothesis AI - Eco_Cost

61,95 €

%leak eliminated		
	5%	991,18
	10%	495,59 €
	20%	247,79 €
	30%	165,20 €
	40%	123,90 €
	50%	99,12 €
	60%	82,60 €
	70%	70,80 €
	80%	61,95 €
	90%	55,07 €
	100%	49,56 €

vi = 991,12- r = 1



4.4.1.5 AI Hypothesis - Costs incurred for AMC

The AMC central software module is used to verify the actual existence of a leak, alert the distributor and user of a possible leak, and calculate gas emissions into the atmosphere. The added value of AMC lies in minimising the number of false positives, whose impact on CBA is significant (Table 10).
AMC could also be delegated, with due precautions, to send commands to the smart meters to intercept the gas supply in cases of safety-related leakage or, for example, in the event of persistent reluctance by the user to eliminate/reduce the significant leakage that they are responsible for.

The set-up and maintenance costs of AMC, evaluated on the basis of market prices of similar solutions, have an impact of more than 50% on the costs for the distributor to manage the function. For the analysis, the annual maintenance cost is estimated as 10% of the set-up cost. The cost of setting up the AMC, which in the reference scenario was quantified around 200,000 Euro, obviously depends on its functions and complexity[38]. AMC costs could also benefit from legislation to regulate the interoperability of additional smart meter functions. The sensitivity analysis in the AI Hypothesis shows that even with an increase of 300% on the assumed cost of AMC, the ROI remains positive. The break-even point (ROI=0) is achieved with an average set-up cost of about 800,000 Euro.

Table 10 - ROI in relation to AMC implementation cost

Hypothesis AI - R O I

AMC set-up cost	ROI
50.000,00 €	1,94
100.000,00 €	1,62
150.000,00 €	1,36
200.000,00 €	1,15
250.000,00 €	0,98
300.000,00 €	0,83
400.000,00 €	0,59
500.000,00 €	0,40
600.000,00 €	0,26
900.000,00 €	-0,03

vi = 1,97- r = 0,9

AMC set-up and maintenance costs are of further significance when considering the country scenario where these costs are multiplied by the 186 distributors operating in the country. Obviously, AMC costs are generally related to the number of users served by the distributor but, in this scenario, the analysis considers an indistinct value for all distributors. The table shows how convenient it would be to pool AMCs among different distributors[39]

[38] AMC could be intended to manage other functions that can be performed through the smart meter, such as supply interruption events in case of earthquakes, fires, profiling of users based on energy footprint, etc.
[39] For example, an independent company that performs the functions of the AMC as a service.

4.4.1.6 AI Hypothesis - Discrimination against false positives

Efficiency in leakage detection also depends on the ability of AMC to discriminate leakage conditions from real consumption conditions ('false positives') and is a significant parameter for ROI (vi=2.07; r=0.45). In the use case considered, even in the event of a false positive, the distributor still bears the cost of the leak test of the user's system.

In AI Hypothesis, an AMC that detects leaks that turn out to be false positives half the time generates an increase in costs that brings the ROI to -14% Table 11); however, in this hypothesis, even inefficient AMCs that generate less than 40% false positives manage to keep the ROI at positive values. The number of false positives that occur should be one of the indicators to be carefully monitored and used to assess the efficiency of an AMC.

Table 11- impact of false positives on the ROI

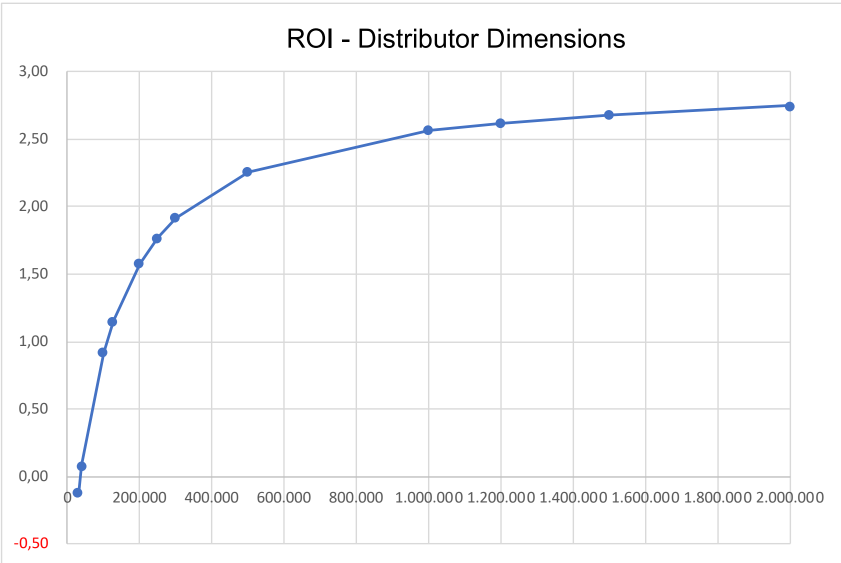
		Hypothesis AI - R O I
Leakage - false positive	0,0%	1,59
	5,0%	1,15
	10,0%	0,84
	20,0%	0,43
	30,0%	0,17
	40,0%	-0,01
	50,0%	-0,14
	60,0%	-0,24
	70,0%	-0,32
	90,0%	-0,44
	100,0%	-0,48
		vi = 2,07- r = 0,45

4.4.1.7 AI Hypothesis - Size of the distribution network

The ROI depends significantly on the size (number of users) of the distribution grid as can be seen from Chart 5. The chart shows how the break-even point (ROI=0) for AI hypothesis is achieved for a grid distributing gas to less than 40,000 households, to which no more than 70,000 m^3 of leaks can be attributed.

Chart 4- ROI by Distribution Grid Size

Hypothesis AI - R O I		
DisCo's Users		Leaks (Mmc)
30.000	-0,12	0,05
40.000	0,08	0,07
100.000	0,92	0,18
126.903	1,15	0,22
200.000	1,58	0,35
250.000	1,77	0,44
300.000	1,92	0,53
500.000	2,26	0,88
1.000.000	2,57	1,76
1.200.000	2,62	2,11
1.500.000	2,68	2,64
2.000.000	2,75	3,52
		vi = 2,87- r = 0,91



4.4.1.8 AI Hypothesis - Social cost of carbon

The assessment of the social cost of carbon or SCC, as mentioned above, is influenced by the discount rate that it is valued at (Table 3). A high discount rate makes it possible to spend less today but passes on the costs of emissions to the heirs. The sensitivity analysis of the ROI in relation to the value of the SCC considered is shown in Chart 6. It is important to note that in the cost-benefit analysis the SCC was kept constant during the observation period at the 2021 value, neglecting the increase of about $1/year also considered in the IWG report.

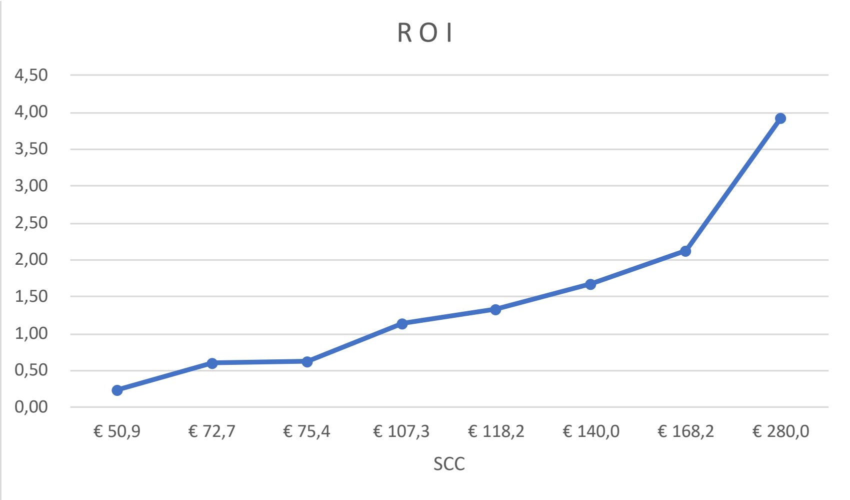
Higher discount rates (lower SCC) lead to a reduction in ROI, but even with IWG's valuations that underestimate the SCC for 2025 ($51 @disc.rate= 3% ; $83 @ disc.rate=2.5%), ROI continues to remain positive . With a discount rate of 1.5 %, the ROI takes on significant values (over 390 percentage points). The break-even point is achieved with an improbable SCC of about $32.

Chart 5 - ROI in relation to adopted SCC value (1€=1.09 $)

Hypothesis AI - R O I

SCC (€/tonCO2eq)		disc.rate
50,9 €	0,24	3% (IWG)
72,7 €	0,60	3,0%
75,4 €	0,64	2,5% (IWG)
107,3 €	1,15	2,5%
118,2 €	1,33	
140,0 €	1,68	
168,2 €	2,14	2,0%
280,0 €	3,94	1,5%

vi = 3,7- r = 1



Furthermore, the analysis shows (Table 12) that irrespective of the size of the network, the SCC parameter plays a significant role in the return on investment. Without taking SCC into account (SCC=0) and thus considering only the benefits from gas savings for Gumbel distribution, no positive ROI values are obtained, whereas for Lognormal distribution in networks with more than 400,000 users in the considered category, raw material recovery would be sufficient to achieve a positive ROI[40].

Table 12 - ROI without carbon cost recovery

Gumbel Distribution — R O I (SCC = 0)

DisCo's Users	
100.000	-0,61
200.000	-0,48
250.000	-0,44
300.000	-0,42
400.000	-0,38
700.000	-0,32
1.200.000	-0,28
1.500.000	-0,26
23.603.958	-0,22

Lognormal Distribution — R O I (SCC = 0)

DisCo's Users	
100.000	-0,64
200.000	-0,36
250.000	-0,24
300.000	-0,13
400.000	0,06
700.000	0,48
1.200.000	0,91
1.500.000	1,08
23.603.958	2,08

[40] This is possible due to the reduced value of investments.

4.4.2 AI-2 Hypothesis for Static Meters ('As Is_2')

Smart meters with mechanical measurement technology cannot change the Q'start and therefore, for these measurement technologies, the capability to intercept small leakage flows cannot be improved with software changes. In Pietro Fiorentini's static meters (which use ultrasonic technology) it is possible to reduce the Q'start via software to values as low as 1.2 dm^3/h. As mentioned, flows of this magnitude are only attributable to leaks and do not occur in normal gas use.

With the hypotheses of the reference scenario (average leakage flow 0.20 dm^3/h, standard deviation 2.2 dm^3/h), the total amount of gas lost with flows between 1.2 and 3 dm^3/h is approximately 38% of the total leakage flows (25% when considering a lognormal probability distribution). These flows, which we underline as only referable to leaks, result in an annual amount of gas that could be worth 10-16 Mm^3 and being partly unaccounted for by the meters contributes, as mentioned in paragraph 5 to the amount of UAFG of the distribution grids[41].

Reducing the Q'start to around 1.2 dm^3/h in current Pietro Fiorentini static meters is technically feasible by placing the measuring module in 'High Resolution (HR)' mode. Constantly keeping the meter in HR mode, however, leads to high battery consumption of the smart meter with a high impact on its service life.

The AI-2 use case assumes that the smart meter only activates the HR mode when it is necessary to verify the existence and extent of a leakage and keeps the mode active for limited periods of time ("Ter") in order to ensure a limited reduction in battery life. Tests carried out on Pietro Fiorentini's meters showed that keeping the ER mode active for no longer than 18 seconds and no more than three times a day would lead to a reduction in battery life of about 3%, equivalent to about 6 months of the 15-year life span[42]. In this hypothesis, it is therefore necessary to take into account the cost of early replacement of the meter due to battery exhaustion before the end of its service life. This additional cost charged to the distributor was estimated by Pietro Fiorentini as being approximately 9 euro per meter[43].

The Cc-1 cost item to realise the software needed for the Pietro Fiorentini smart meter function is estimated to be around 250 K€.

The solution of the AI-2 hypothesis allows the gas of leaks to be accounted for, but only during the 'Ter' period, especially those that cannot be fixed, representing an additional, albeit small, benefit attributed in the CBA to the seller as stated in Table 13.

With the same reference scenario, the AI-2 hypothesis shows a significant reduction in ROI compared to the AI hypothesis solution, a reduction mainly due to increases in the costs incurred by the distributor resulting from the reduction in the useful life of the meter and the increase in costs for handling intercepted leaks[44]. The main benefit related to emission reductions over the observation period (**32 $KtCO_2eq$**) is higher than that assumed with the solution of the AI hypothesis (19 $KtCO_2eq$).

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41 Unaccounted-for gas on the Italian grids is about 695 Mm3 (Source: UNICASSINO Study -2017)
42 Evaluations carried out on measurement technologies of some manufacturers
43 Calculated with an updated standard cost value (TS=4.5%) of the meter of 150 €
44 The number of users to whom a leak is attributed increases, which must be managed

Table 13 - ROI for AI-2 hypothesis

Community	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 3.269.789	€ -	€ (3.269.789)	€ 26	€ -
GasCo	€ -	€ 139	€ 139	€ -	€ 0
Community	€ -	€ 4.260.699	€ 4.260.699	€ -	€ 34
Total	€ 3.269.789	€ 4.260.838	€ 991.049	€ 26	€ 34
R O I	**0,30**				
R O Ics	**4,4%**				
Eco_Cost	**102,66 €**				
%AE	**52,8%**	***Avoided Emissions (tCO2eq)***	**31.849**		

Of the costs incurred by the distributor, 40% are capital costs (CAPEX), of which 33% are attributable to the reduction in meter life, while 32% are operating costs (OPEX) incurred in the verification and suspension of supply.
In terms of community benefits, almost 20% is the benefit attributable to methane saved and 80% attributable to SCC avoided. The benefit attributed to the seller for the recovery of unaccounted-for gas, as anticipated, is not significant (0.003%)

ROI stands at 30% and ROI$_{cs}$ at over 4%. The Ecological Cost is over 102 €/tonCO2eq while the efficacy of the solution (%AE) is 53%

The sensitivity analysis revealed the following major criticalities for the AI-2 Hypothesis:

✓ *Distribution grid size* - compared to the AI solution, the AI-2 solution starts to be advantageous (ROI >0) for distribution grids with more than 60,000 users.

Hypothesis AI 2- R O I

DisCo's Users		Perdite (Mmc)
35.000	-0,08	0,06
60.000	0,10	0,11
100.000	0,24	0,18
126.903	0,30	0,22
200.000	0,38	0,35
250.000	0,41	0,44
300.000	0,43	0,53
500.000	0,48	0,88
1.000.000	0,52	1,76
1.200.000	0,52	2,11
1.500.000	0,53	2,64
2.000.000	0,53	3,52

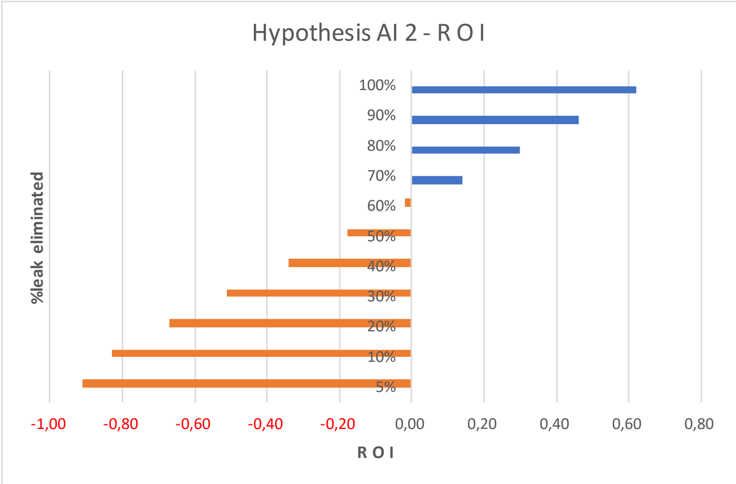
✓ *Repaired leaks* - the ROI of the AI-2 hypothesis remains negative until at least 60% of the leaks are fixed.

Hypothesis AI 2 - R O I

0,30 €

%leak eliminated	
5%	-0,91
10%	-0,83
20%	-0,67
30%	-0,51
40%	-0,34
50%	-0,18
60%	-0,02
70%	0,14
80%	0,30
90%	0,46
100%	0,62

vi = 1,53- r = 0,36



✓ *False positives* - the ROI of the AI-2 hypothesis is significantly affected by false positives; 15% false positives are sufficient to cancel out the ROI.

Hypothesis AI 2 - R O I

Leakage - false positive	
0,0%	0,54
5,0%	0,30
10,0%	0,12
15,0%	0,00
20,0%	-0,11
40,0%	-0,38
50,0%	-0,46
60,0%	-0,52
70,0%	-0,57
90,0%	-0,64
100,0%	-0,67

vi = 1- r = 0,9

4.4.3 CB Hypothesis ('COULD BE')

The 'Could Be' hypothesis analyses the solution that considers the design and implementation of a new smart meter (with ultrasonic static measurement technology) capable of measuring gas flows from 1 dm^3/h (Qstart) and up to 10m^3/h (Qmax). The meter would then have significant '*rangeability*' (R=Qmax/Qstart = 10,000).

Assessments on the feasibility of this hypothesis, carried out by Pietro Fiorentini, estimate the development costs of this new smart meter at around 1.4 M€ and an increase in the price of the smart meter between 12 and 15 €.

The new smart meter would allow gas flows of 1 dm^3/h (Qstart) or more to be detected and measured in accordance with the MID directive, which we recall are typical leakage rates and are not attributable to normal user consumption. Thus, the gas lost in the post-meter system can not only be largely detected but also measured. With Gumbel's density distribution, the users affected by leaks of more than 1 dm^3/h would be only 30% (4% with the lognormal distribution) but these few users would be responsible for more than 90% of the leaks (53% for the lognormal distribution). Unlike the AI-2 hypothesis, the CB hypothesis reduces the Qstart but does not temporally limit the HR period and does not reduce the lifetime of the smart meter.

The CBA for this hypothesis, in the reference scenario, provides the following results:

Hypothesis CB - (single distribution network scenario)	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 3.676.105	€ -	€ (3.676.105)	€ 29	€ -
GasCo	€ -	€ 15.067	€ 15.067	€ -	€ 0
Community	€ -	€ 4.419.685	€ 4.419.685	€ -	€ 35
Total	**€ 3.676.105**	**€ 4.434.752**	**€ 758.646**	**€ 29**	**€ 35**

R O I	**0,20**			
R O Ics	**3,3%**			
Eco_Cost	**111,27 €**			
%AE	**54,7%**	***Avoided Emissions (tCO2eq)***	**33.038**	

Of the costs incurred by the distributor, 42% are capital costs (CAPEX), of which 36% are attributable to the additional cost of the meter, while 32% are operating costs (OPEX) incurred for verification and suspension of supply. The benefit to the community in terms of methane saved is over 19% and almost 80% attributable to avoided SCC; the benefit (to the seller) from the recovery of unaccounted-for gas is over 0.3%.
ROI stands at 20% and ROI_{CS} at 3%; the Ecological Cost would grow to over 111 €/tonCO_2eq. The %AE (solution efficacy) **index increases to almost 55%**

The solution in the reference scenario would avoid about 55% of emissions, which in the country scenario, where all meters adopt the CB scenario solution, would avoid about **6 million** tonnes of CO_2 equivalent.

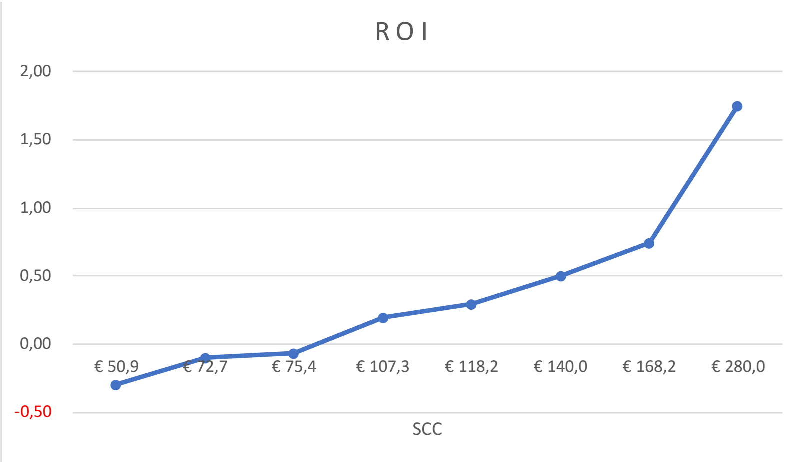
In this hypothesis, SCC significantly affects ROI as indicated in Chart 7: ROI is cancelled when SCC is estimated at the value of $83 indicated by IWG.

Chart 6 - Influence of SCC on ROI in the CB hypothesis

Hypothesis CB - R O I

SCC (€/tonCO2eq)		*disc.rate*
50,9 €	-0,30	*3% (IWG)*
72,7 €	-0,10	*3,0%*
75,4 €	-0,07	*2,5% (IWG)*
107,3 €	0,20	*2,5%*
118,2 €	0,30	
140,0 €	0,50	
168,2 €	0,75	*2,0%*
280,0 €	1,75	*1,5%*

vi = 2,05- r = 0,66



4.5 Alternative method for post-meter leak reduction

An alternative method of detecting fugitive leaks that does not involve investment is to periodically check the tightness of each user's system (VP Hypothesis). Regardless of the difficulty of getting users to test their own systems, there are national reference standards[45] that establish test methods, minimum test times and criteria for defining the extent of the leakage.

The CBA of the VP hypothesis considers the reference scenario described in Table 19, which provides for a minimum test duration as indicated by the regulations. The analysis is carried out considering the reference distribution grid (126,903 users); if the entire country is considered, the absolute values must be multiplied by the number of grids belonging to the 186 distributors. The use case in support of VP Hypothesis assumes that it is the user who has a leakage test done on their system every 2 years[46]. The reference scenario assumes, according to the Gumbel distribution, that post-meter leaks of more than 1 dm^3/h are 91% of the total leaks (53% according to lognormal distribution).

The use case assumes that all network users have their systems checked[47] and, if a leakage of more than 1 dm^3/h is detected, at least 80% of them will repair it, as in the other cases.

The CBA of the VP hypothesis assumes that the leaks are all intercepted in the first testing period and equally distributed over the period; the benefits of interception are maintained for the remaining years until the end of the observation period[48].

The CBA summarised in Table 15 shows a negative ROI and an 'ecological cost' over 15 years of more than **€455/tCO_2eq.** The ROI trend and avoided emission quantities change with varying checking frequency as shown in Chart 8. The method, under the hypotheses of the reference scenario, could avoid about 26 KtCO_2eq of emissions.

However, the VP hypothesis, compared to the CB hypothesis, does not induce any UAFG savings for the leaks that are not resolved. In addition, with the alternative method of the VP hypothesis, the average persistence time of a leak ('tp') is higher (50% of the testing frequency) than with the use of smart meters (2-3 months), which, with the data from Table 4, results in a cost to the community of almost 23€/year for each dm^3 of leakage.

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[45] UNI 11137 and UNI 10738

[46] It is assumed that the system tightness check is conducted at the same time as the combustion analysis and flue gas inspection (carbon monoxide), which became compulsory in Italy with Presidential Decree 74/2013; the simultaneous occurrence of the two checks results in savings for the user.

[47] The reduction in emissions is proportional to the number of users who test their system

[48] In the case of a two-year audit and the reference scenario, 31 Mm3 of methane is intercepted within the first two years and an additional 31 Mm3 per year is saved in the following 13 years.

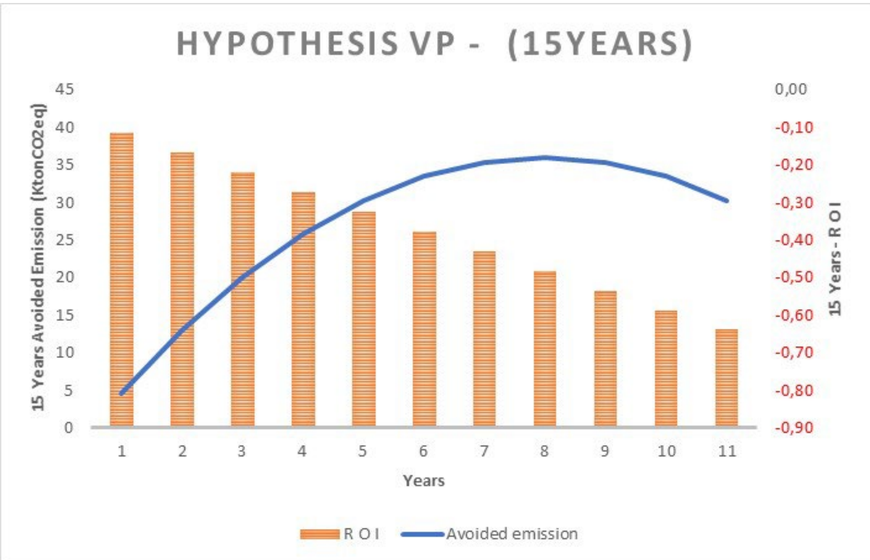
Table 14 - Reference Scenario - VP Hypothesis

Reference Scenario	
SCC - Social Cost of carbon	**107,30** €/tCO2eq
Average Gas Natural Price	**0,90** €/mc
Test Frequency	**2** year
Users(G2,5-G6)	**126.903**
Yearly Gas Leakages (G2,5_G6)	**0,22** Mmc
Test duration	**30** minutes
Test costs per hour	**35,00** €
Leaks intercepted (>1dmc/h)	**91,2%**
Tests performed	**100,0%**
Leaks eliminated	**80,0%**

Table 15- ROI and Efficacy of the VP Hypothesis

Costs - Benefits Analysis	In 1 year		In 15 years	
Costs				
Test Cost (pro user)	8,75 **€**		131,25 €	
Total Costs	**1,11** M€		**16,66** M€	
Benefits				
Avoided CO2 Emissions	**1,31** KtCo2eq		**36,60** KtCo2eq	
Avoided Natural Gas Emissions	**0,08** Mmc		**2,28** Mmc	
Avoided SCC	**0,14** M€		**3,93** M€	
Avoided Natural Gas Costs	**0,07** M€		**2,05** M€	
Total Benefts	**0,21** M€		**5,98** M€	
ROI	**-0,81**		**-0,64**	
Eco_Cost	**849,39**	€/tCO2eq	**455,03**	€/tCO2eq
%AE	**34,7%**		**64,7%**	

Chart 7 - ROI and Emissions as a function of checking frequency



4.6 Comparison of hypotheses

Table 16 compares the results of Pietro Fiorentini's CBA for the different hypotheses in the reference scenario, observation period and reference distributor perspective.

The following are compared: the "ROI", which takes into account the financial aspect, the "Avoided Emissions" expressed in thousands of tonnes of CO_2 equivalent, which determine the efficiency of the hypothesis, the investments expressed in millions of euros that the country system would have to bear during the observation period, and the "Ecological Cost", expressed as the cost to be borne to eliminate one tonne of CO2 equivalent, which together with the ROI determine the efficiency of each hypothesis.

The solution based on the AI hypothesis is the most efficient solution compared to the other two solutions based on the AI-2 and CB hypotheses, which are almost equivalent to each other.

The solution based on the VP hypothesis is much more effective than the AI hypothesis but only 18% more effective than the CB hypothesis. The annual average total costs of the VP hypothesis amount to 1.1 M€ while the annual average total costs of the CB hypothesis amount to 0.25 M€.

Considering the solutions using smart meters, if from a financial point of view, the AI hypothesis is the most efficient in economic terms, the solution using the CB hypothesis is the most effective: avoided emissions twice as high as with the AI hypothesis.

Table 16- Comparison of hypotheses

	ROI	***%AE***	***Investments (M€)***	***Eco_Cost (€/tCO2eq)***	***Relative Effectiveness***	***Relative Efficiency***
Hypothesis AI	1,15	0,32	1,2	61,95	1,00	1,00
Hypothesis AI-2	0,30	0,53	3,3	102,66	1,67	0,60
Hypothesis CB	0,20	0,55	3,7	111,27	1,73	0,56
Hypothesis VP	-0,64	0,65	16,7	455,03	2,05	0,14

Regarding the value of the smart metering function, the ROIcs for all hypotheses is over ***3%*** with the AI hypothesis prevailing (around 7%).

4.7 Smart meter upgrade

The reference scenario assumes for any hypothesis that the installation of the new smart meters with the leakage detection function takes place without any reduction in the residual value of the already installed meter[49]. It must also be considered that the measurement technologies envisaged by the AI and AI-2 hypotheses are already available[50] and the solutions envisaged by the two hypotheses for the necessary system could in turn be made available in a short time.

As a further consideration, the firmware of many smart meters currently in operation could be upgraded (realistically even remotely)[51] so as to achieve functionality equivalent to that contemplated in the AI and AI-2 hypotheses. With the upgrade, solutions that effectively support the reduction of methane emissions could be available in a short time. Upgrading the software of existing smart meters that are not nearing the end of their metrological life, even if done remotely, is estimated by Pietro Fiorentini to cost 25€cent per user, and the CBA also estimates that for 10% of users the remote upgrade fails and therefore requires local intervention.

With these premises, the CBA for the AI hypothesis, which assumes the upgrading of existing smart meters, provides the following results:

Hypothesis AI - (single distribution network scenario)	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 1.388.085	€ -	€ (1.388.085)	€ 11	€ -
GasCo	€ -	€ -	€ -	€ -	€ -
Community	€ -	€ 2.549.522	€ 2.549.522	€ -	€ 20
Total	**€ 1.388.085**	**€ 2.549.522**	**€ 1.161.438**	**€ 11**	**€ 20**

R O I	**0,83**			
R O Ics	**5,7%**			
Eco_Cost (€/tCO2eq)	**72,83 €**			
%AE	**31,6%**	***Avoided Emissions (tCO2eq)***	**19.058**	

Firmware upgrade costs account for 17% of investments; the ROI of the AI hypothesis is reduced to 83% and the ROI_{SC} is reduced to less than 6%.

Software upgrades adapting the already installed smart meters to the AI Hypothesis can be carried out in a shorter time than the 5 years foreseen in the reference scenario with a consequent increase in ROI and avoided emissions[52] as shown by Table 17.

[49] That is, the cost associated with the residual value of the meter being decommissioned is not considered
[50] Please note that AI-2 hypothesis does not foresee the use of smart meters with mechanical measurement technology
[51] Pietro Fiorentini verified the upgradeability of some firmware versions of its meters.
[52] Each year's advance results in a 7% increase in ROI and 110 KtCO2eq of avoided emissions

Table 17 - ROI and Avoided emissions in relation to meter upgrade years

Hypothesis AI - R O I & Avoided Emissions

Smart Meters Rollout (years)	R O I	Avoided Emission (ktCO2eq)
1	1,01	22,23
2	0,97	21,44
3	0,92	20,65
4	0,88	19,85
5	0,83	19,06
6	0,78	18,26
7	0,73	17,47
8	0,68	16,68
9	0,62	15,88
10	0,57	15,09

For the AI-2 hypothesis assuming the firmware update of the already installed smart meters, the CBA provides the following results:

Community	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 3.471.199	€ -	€ (3.471.199)	€ 27	€ -
GasCo	€ -	€ 139	€ 139	€ -	€ 0
Community	€ -	€ 4.260.699	€ 4.260.699	€ -	€ 34
Total	€ 3.471.199	€ 4.260.838	€ 789.639	€ 27	€ 34
R O I	**0,22**				
R O Ics	**3,5%**				
Eco_Cost	**108,99 €**				
%AE	**52,8%**	***Avoided Emissions (tCO2eq)***		**31.849**	

The AI and AI-2 hypotheses could be further justified if other functions that add value but do not require hardware changes (e.g. alarms on significant events, cardless pre-payment, etc.) are assumed to be implemented in the smart meter. The CBA of these features should still be evaluated.

The measurement technology required for the CB Hypothesis, on the other hand, has yet to be developed and, according to Pietro Fiorentini, it could take 18-30 months to make it available in their equipment.

The CB hypothesis is further justified if other functions are implemented in the smart meter that add further value but require hardware modifications, such as: dual remote communication channels, direct communication with the user (Chain2), energy measurement, seismic event detection, etc.

The CB hypothesis envisages, once available, installing the new smart meters in place of traditional[53] meters still in use or proceeding with the installation of the new smart meters in the event of failure of existing meters or at the end of their metrological life. The solution envisaged for the CB hypothesis does not in fact provide for the upgrade of existing meters.

For the CB hypothesis, on the other hand, the use case was analysed in which the new smart meter replaces a meter in service before the end of its metrological life. The scenario assumes that in the first year in which replacement begins, the existing smart meters have already been in operation for 7 years and that each remaining year of operation is worth €10[54] for each uninstalled meter. Under these assumptions, the cost-benefit analysis for the CB hypothesis yields the following results:

Hypothesis CB - (single distribution network scenario)	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 10.764.570	€ -	€ (10.764.570)	€ 85	€ -
GasCo	€ -	€ 15.067	€ 15.067	€ -	€ 0
Community	€ -	€ 4.419.685	€ 4.419.685	€ -	€ 35
Total	**€ 10.764.570**	**€ 4.434.752**	**€ (6.329.818)**	**€ 85**	**€ 35**

R O I	**-0,58**			
R O Ics	**-21,2%**			
Eco_Cost	**325,82 €**			
%AE	**54,7%**	***Avoided Emissions (tCO2eq)***	**33.038**	

Early replacement of smart meters accounts for 66% of the investment; ROI is negative (-58%) and remains negative, however the variables on which it depends change in the significant range; ROI_{cs} is -21%; ecological cost rises to 326 €/tCO_2eq. Efficacy is almost 55%

[53] In 2022, there were still about 4 million non-smart meters of less than G10 gauge
[54] One fifteenth of the standard cost

5. Reduction of Unaccounted for Gas (UAFG) in distribution grids

The solution of the CB hypothesis, as seen, generates as an additional benefit, a recovery of unaccounted-for gas (UAFG) from the gas distribution grids. UAFG[55] has wide implications for regulatory practices as it combines technical and commercial leaks and affects the cost of gas supply, safety of service as well as environmental impact. In addition to unmetered gas, UAFG includes 'linepack' changes, i.e. gas accumulated in the grid (considered negligible in distribution grids), leaks and emissions from the grid, fraudulent withdrawals and shortages in general.

As reported in Chart 9 the UAFG[56] of distribution grids is assessed as being 2.5% of the distributed gas while post-meter leaks are estimated at 6.1% of the total UAFG.

The post-meter leaks included between 1 dm^3/h (Qstart of the CB hypothesis) and 3dm^3/h (Q'start of the current metering systems) in the reference scenario are estimated to be over 39% (25% according to the lognormal distribution) of the total post-meter leaks. These flows, when they are the only flows passing through the meter[57], are not currently measured. In the CB hypothesis in which leaks with a flow of between 1 and 3 dm^3/h are measured, the amount of gas, which is currently not measured but could be accounted for if all meters adopted the CB hypothesis, could be more than 2.4 Mm^3 of gas, i.e. more than 0.3 % of the UAFG of the distribution grids. Even under the unfavourable hypothesis of an always positive measurement uncertainty of 10%, the recovery would still amount to over 2 Mm^3.

Chart 8

			Font
Gas distributed	28.316	Mmc	*ARERA - Annual report 2022*
Distribution Unaccounted Gas (GNC)	695	Mmc	*2017 data from UNICASSINO*
Post Meter Gas Leakage	42,4	Mmc	*ISPRA report 383-2023*
Post Meter Gas Leakage (G2,5-G6)	41,5	Mmc	*computation*
Users	24,1	Mu	*ARERA - Annual report 2023*
Users (G2,5-G6)	23,6	Mu	*ARERA - Annual report 2024*
Accounted Gas (Leakage 1-3 dmc/h)	**2,40**	**Mmc**	*computation*

[55] UAFG is defined as the absolute difference between the volume of gas entering the system (measured or estimated at the entry point) and that leaving the system (measured or estimated at the exit points).
[56] The UAFG calculated by UNICASSINO refers to the year 2017; the other figures refer to 2022
[57] During the period when the user does not consume gas, which is estimated in the CBA at 15% of the day.

6. Statistical inference

The analysis presented in this paper highlights the efficacy of smart meters in supporting the detection, metering and reduction of methane leaks occurring in post-meter distribution systems considering the hypotheses of the reference scenario.

The analysis highlighted the usefulness of having reliable data based on actual measurements for post-meter leaks in the home distribution segment. Since it is not feasible to carry out direct measurements on all systems, it is necessary to activate a statistical inference procedure[58] which requires defining a representative sample to carry out measurements on. The measurements are useful to confirm the assumptions of the reference scenario, and particularly the mean value of the leaks, the standard deviation, and the most representative probability distribution of the phenomenon.

The representative sample size is a function of the population and of the acceptable error for inference as shown in Table18 obtained considering a 99% sample confidence level and a (conservative) standard deviation of 50%. The table shows that for the distribution grid of the reference scenario (approx. 130,000 households), if a statistical error[59] of inference of no more than 1% is to expected, a sample of no less than 14,800 users randomly selected from those served is required. At the country level, each distributor would then have to select a random sample of users in relation to the size of its grid and what Table18 indicates, but overall, a sample of 17,000 users, or 67,000 if one tends towards an error of 0.5%, would be sufficient to extend the inferential procedure to the entire country.

The choice of the statistical sample can be made in two different ways:

a) Simple random sampling: the statistical sample is determined by considering all household users with the same probability of post-meter emissions. The sample to be measured is drawn randomly from the list of users regardless of the gas use category (C1, C2, C3; Table 20)
b) Stratified random sampling: the statistical sample is determined by taking into account that there may be differences between the various categories of gas use (C1, C2, C3)[60] both in terms of the probability of occurrence and the extent of leakage.
c) With a population of 23.7 M users, a (conservative) standard deviation of 0.5 and a confidence level of 99%, in the case of simple random sampling and as a function of the objective error, the sample size is as shown in Table 19.

Even in the case of stratified sampling according to gas use category, the statistical sample should be no less than 16,600 and 4,200 units respectively for each category, in relation to the accepted error of 1% or 2% respectively, as stated in Table 20.

[58] Inferential statistics is the process by which the characteristics of a population are deduced from the observation of random samples

[59] The error indicates how likely it is that the survey results reflect the views of the population as a whole. The smaller the error, the greater the probability of getting the correct answer with a given level of confidence. As an example, if we use a margin of error of 1% and the result of the sample survey is 47%, we can be sure with 99% confidence that the result is between 46% and 48%

[60] The different categories correspond to generally more articulated post-meter gas distribution systems, with more user devices and a different probability of leakage. Some studies in the USA associate the amount of post-meter leakage with the number of gas-powered devices.

Table18 - Minimum statistical sample size

Minimum Sample	Error									
Domestic Users (G2,5-G6)	**0,50%**	**1%**	**1,50%**	**2%**	**2,50%**	**3%**	**3,50%**	**4%**	**4,50%**	**5%**
50.000	57,1051%	24,9711%	12,8859%	7,6814%	5,0559%	3,5661%	2,6450%	2,0377%	1,6170%	1,3138%
60.000	52,5932%	21,7129%	10,9739%	6,4842%	4,2490%	2,9895%	2,2140%	1,7039%	1,3511%	1,0972%
100.000	39,9630%	14,2669%	6,8867%	3,9941%	2,5935%	1,8154%	1,3402%	1,0294%	0,8151%	0,6612%
130.000	33,8638%	11,3481%	5,3830%	3,1010%	2,0070%	1,4024%	1,0342%	0,7937%	0,6282%	0,5094%
200.000	24,9711%	7,6814%	3,5661%	2,0377%	1,3138%	0,9160%	0,6746%	0,5173%	0,4092%	0,3317%
250.000	21,0270%	6,2410%	2,8734%	1,6369%	1,0538%	0,7342%	0,5404%	0,4143%	0,3276%	0,2655%
300.000	18,1589%	5,2555%	2,4060%	1,3678%	0,8797%	0,6126%	0,4508%	0,3455%	0,2732%	0,2214%
500.000	11,7487%	3,2210%	1,4576%	0,8252%	0,5297%	0,3684%	0,2710%	0,2076%	0,1641%	0,1330%
1.000.000	6,2410%	1,6369%	0,7342%	0,4143%	0,2655%	0,1846%	0,1357%	0,1039%	0,0821%	0,0665%
1.200.000	5,2555%	1,3678%	0,6126%	0,3455%	0,2214%	0,1538%	0,1131%	0,0866%	0,0684%	0,0554%
1.500.000	4,2490%	1,0972%	0,4906%	0,2766%	0,1772%	0,1231%	0,0905%	0,0693%	0,0548%	0,0444%
2.000.000	3,2210%	0,8252%	0,3684%	0,2076%	0,1330%	0,0924%	0,0679%	0,0520%	0,0411%	0,0333%
23.604.000	0,2812%	0,0705%	0,0313%	0,0176%	0,0113%	0,0078%	0,0058%	0,0044%	0,0035%	0,0028%

Table 19- Simple statistical sample size

Sample	Error
66.378	0,50%
16.629	1,00%
7.394	1,50%
4.160	2%

Table 20- Stratified statistical sample size

Gas Use for		*users*	*sample (e=1%)*	*sample (e=2%)*
C1-Heating	2,17%	523.035	16.128	4.127
C2- Cooking + water heater	42,31%	10.197.979	16.614	4.159
C3 - Heat.+water heat.+cook.	53,97%	13.008.389	16.620	4.159
ToT	98,45%	23.729.404		

The costs to organise the interventions, to carry out the tests and to process the statistical data for a sample of 67,000 users were estimated by Pietro Fiorentini to be around Euro 4.7 million, i.e. a contribution of 20€cent per household. If this contribution is also considered, the CBA of the AI Hypothesis, which also considers the firmware update of existing smart meters, yields the following results:

Hypothesis AI - (single distribution network scenario)	COSTS (C)	BENEFITS (B)	C-B	Cost per capita	Benefit per capita
DSO	€ 1.416.915	€ -	€ (1.416.915)	€ 11	€ -
GasCo	€ -	€ -	€ -	€ -	€ -
Community	€ -	€ 2.549.522	€ 2.549.522	€ -	€ 20
Total	**€ 1.416.915**	**€ 2.549.522**	**€ 1.132.607**	**€ 11**	**€ 20**

R O I	**0,79**			
R O Ics	**5,5%**			
Eco_Cost (€/tCO2eq)	**74,35 €**			
%AE	**31,6%**	***Avoided Emissions (tCO2eq)***	**19.058**	

The cost for statistical inference represents 2% of the costs incurred during the period.

ROI is reduced to 80%, ROI_{CS} to 5%, the ecological cost increases to 74€/tCO_2eq.

7. APPENDIX – A

The probability distribution of leaks affects the CBA.

Narrowing the field of interest to two-factor leak flow probability distribution functions, these are characterised by the mean - μ - and the standard deviation - σ -. The mean is related to the estimate of total natural gas emissions (*Tot_em*) in post-meter systems; the standard deviation, in the CBA analysis, was related to the maximum leakage considered q_{leak_max}, meaning that at least 99% of the gas leaks due to leakage are less than q_{leak_max}. The correlation of the ROI, avoided emissions and ecological cost of the AI Hypothesis (considered the most efficient) to the estimated total leaks in the post-meter grids and the value of Qleak_max, for the two probability distributions analysed, are shown in the tables below.

Table 21 - ROI of the AI Hypothesis as a function of Tot_em and standard deviation (Gumbel distribution)

Hypothesis AI - R O I										
	Average (mc/y)	0,42	0,85	1,27	1,80	2,12	2,54	2,97	3,39	3,81
		Total Natural Gas Leakage (Mmc)								
		10	20	30	42,4	50	60	70	80	90,00
standard deviation (dmc/h)	0,6	-0,97	-0,94	-0,91	-0,87	-0,85	-0,81	-0,78	-0,74	-0,71
	0,8	-0,89	-0,79	-0,68	-0,55	-0,46	-0,35	-0,23	-0,12	0,00
	1	-0,79	-0,58	-0,36	-0,10	0,05	0,26	0,47	0,68	0,90
	1,2	-0,68	-0,37	-0,06	0,30	0,53	0,83	1,13	1,42	1,71
	1,4	-0,60	-0,21	0,16	0,63	0,91	1,28	1,63	1,99	2,33
	1,6	-0,54	-0,10	0,33	0,86	1,17	1,58	1,99	2,38	2,77
	1,8	-0,50	-0,02	0,44	1,01	1,35	1,79	2,22	2,64	3,05
	2	-0,48	0,01	0,50	1,10	1,46	1,92	2,37	2,80	3,23
	2,2	-0,47	0,04	0,54	1,15	1,52	1,99	2,45	2,90	3,34
	2,4	-0,46	0,05	0,56	1,18	1,55	2,03	2,50	2,95	3,40
	2,6	-0,46	0,06	0,57	1,19	1,57	2,05	2,52	2,98	3,43
	2,8	-0,46	0,06	0,57	1,19	1,56	2,05	2,52	2,98	3,43
	3	-0,46	0,05	0,56	1,18	1,55	2,03	2,51	2,97	3,42

Table 22a - ROI of the AI Hypothesis as a function of Tot_em and standard deviation (Lognormal Distribution)

Hypothesis AI - R O I										
	Average (mc/y)	0,42	0,85	1,27	1,80	2,12	2,54	2,97	3,39	3,81
		Total Natural Gas Leakage (Mmc)								
		10	20	30	42,4	50	60	70	80	90,00
standard deviation (dmc/h)	0,6	-0,71	-0,42	-0,19	0,03	0,13	0,24	0,31	0,37	0,40
	0,8	-0,66	-0,30	0,01	0,37	0,57	0,80	1,00	1,18	1,34
	1	-0,63	-0,22	0,16	0,61	0,86	1,18	1,47	1,74	2,00
	1,2	-0,61	-0,17	0,26	0,77	1,07	1,45	1,80	2,14	2,46
	1,4	-0,59	-0,12	0,34	0,90	1,23	1,64	2,04	2,43	2,79
	1,6	-0,58	-0,09	0,40	1,00	1,35	1,80	2,23	2,65	3,05
	1,8	-0,57	-0,06	0,45	1,08	1,45	1,92	2,38	2,82	3,25
	2	-0,56	-0,03	0,49	1,14	1,53	2,03	2,51	2,97	3,42
	2,2	-0,55	-0,01	0,53	1,20	1,60	2,11	2,61	3,09	3,56
	2,4	-0,54	0,00	0,56	1,25	1,66	2,19	2,70	3,19	3,67
	2,6	-0,54	0,01	0,59	1,29	1,71	2,25	2,78	3,28	3,78
	2,8	-0,53	0,03	0,61	1,32	1,75	2,31	2,84	3,36	3,87
	3	-0,52	0,04	0,63	1,36	1,80	2,36	2,90	3,43	3,95

Table 23 - Emissions avoided with the AI Hypothesis as a function of Tot_em and standard deviation (Gumbel distribution)

Hypothesis AI - %Avoided Emissions

Average (mc/y)	0,42	0,85	1,27	1,80	2,12	2,54	2,97	3,39	3,81
	Total Natural Gas Leakage (Mmc)								
standard deviation (dmc/h)	**10**	**20**	**30**	**42,40**	**50**	**60**	**70**	**80**	**90**
0,6	0,82%	0,84%	0,85%	0,87%	0,88%	0,90%	0,92%	0,94%	0,0097
0,8	3,21%	3,24%	3,28%	3,33%	3,36%	3,41%	3,46%	3,52%	0,04
1	7,00%	7,06%	7,12%	7,20%	7,25%	7,33%	7,41%	7,49%	0,08
1,2	11,51%	11,58%	11,66%	11,77%	11,83%	11,92%	12,02%	12,12%	0,12
1,4	16,15%	16,23%	16,32%	16,43%	16,51%	16,60%	16,71%	16,82%	0,17
1,6	20,56%	20,65%	20,74%	20,86%	20,93%	21,04%	21,14%	21,25%	0,21
1,8	24,59%	24,68%	24,77%	24,88%	24,96%	25,06%	25,16%	25,26%	0,25
2	28,17%	28,25%	28,34%	28,45%	28,52%	28,62%	28,71%	28,81%	0,29
2,2	31,31%	31,39%	31,47%	31,57%	31,64%	31,73%	31,82%	31,91%	0,32
2,4	34,03%	34,11%	34,18%	34,28%	34,34%	34,42%	34,50%	34,59%	0,35
2,6	36,39%	36,46%	36,53%	36,62%	36,67%	36,75%	36,82%	36,90%	0,37
2,8	38,43%	38,49%	38,55%	38,63%	38,69%	38,75%	38,82%	38,89%	0,39
3	40,19%	40,24%	40,30%	40,38%	40,42%	40,49%	40,55%	40,61%	0,41

Table 24a - Emissions avoided with the AI Hypothesis as a function of Tot_em and standard deviation (Lognormal distribution)

Hypothesis AI - %Avoided Emissions

Average (mc/y)	0,42	0,85	1,27	1,80	2,12	2,54	2,97	3,39	3,81
	Total Natural Gas Leakage (Mmc)								
standard deviation (dmc/h)	**10**	**20**	**30**	**42,40**	**50**	**60**	**70**	**80**	**90**
0,6	8,63%	8,72%	8,28%	7,57%	7,11%	6,53%	5,98%	5,47%	0,0501
0,8	9,91%	10,54%	10,54%	10,29%	10,07%	9,76%	9,44%	9,11%	0,09
1	10,81%	11,78%	12,08%	12,15%	12,11%	12,03%	11,91%	11,77%	0,12
1,2	11,48%	12,69%	13,19%	13,48%	13,58%	13,65%	13,68%	13,70%	0,14
1,4	12,00%	13,39%	14,04%	14,49%	14,68%	14,86%	15,01%	15,12%	0,15
1,6	12,43%	13,95%	14,71%	15,28%	15,54%	15,80%	16,03%	16,22%	0,16
1,8	12,79%	14,41%	15,26%	15,92%	16,22%	16,56%	16,84%	17,09%	0,17
2	13,10%	14,79%	15,71%	16,45%	16,79%	17,17%	17,50%	17,79%	0,18
2,2	13,36%	15,12%	16,09%	16,89%	17,27%	17,69%	18,05%	18,37%	0,19
2,4	13,60%	15,41%	16,43%	17,27%	17,67%	18,12%	18,51%	18,86%	0,19
2,6	13,80%	15,66%	16,72%	17,60%	18,02%	18,50%	18,91%	19,29%	0,20
2,8	13,99%	15,89%	16,97%	17,89%	18,33%	18,83%	19,26%	19,65%	0,20
3	14,16%	16,09%	17,20%	18,15%	18,60%	19,11%	19,56%	19,97%	0,20

Table 25 - Ecological_cost of the AI Hypothesis as a function of Tot_em and standard deviation (Gumbel distribution)

Hypothesis AI - R O I - Eco_Cost (€/tCO2eq)

Average (mc/y)	0,42	0,85	1,27	1,80	2,12	2,54	2,97	3,39	3,81
				Total Natural Gas Leakage (Mmc)					
standard deviation (dmc/h)	**10**	**20**	**30**	**42,4**	**50**	**60**	**70**	**80**	**90**
0,6	4.834,04 €	2.384,22 €	1.565,97 €	1.085,68 €	908,26 €	742,50 €	623,33 €	533,29 €	462,68 €
0,8	1.290,76 €	641,06 €	424,32 €	297,38 €	250,62 €	207,06 €	175,86 €	152,40 €	134,09 €
1	637,56 €	318,53 €	212,18 €	149,96 €	127,08 €	105,80 €	90,59 €	79,18 €	70,30 €
1,2	427,94 €	214,79 €	143,76 €	102,23 €	86,97 €	72,79 €	62,67 €	55,08 €	49,19 €
1,4	339,36 €	170,87 €	114,73 €	81,92 €	69,87 €	58,67 €	50,68 €	44,70 €	40,05 €
1,6	295,91 €	149,28 €	100,43 €	71,88 €	61,40 €	51,66 €	44,71 €	39,51 €	35,47 €
1,8	272,85 €	137,80 €	92,81 €	66,52 €	56,86 €	47,88 €	41,49 €	36,70 €	32,98 €
2	260,27 €	131,52 €	88,62 €	63,55 €	54,34 €	45,79 €	39,69 €	35,12 €	31,57 €
2,2	253,56 €	128,16 €	86,37 €	61,95 €	52,98 €	44,64 €	38,69 €	34,24 €	30,79 €
2,4	250,38 €	126,54 €	85,28 €	61,16 €	52,30 €	44,06 €	38,19 €	33,79 €	30,37 €
2,6	249,39 €	126,02 €	84,91 €	60,88 €	52,05 €	43,84 €	37,99 €	33,60 €	30,20 €
2,8	249,80 €	126,19 €	85,00 €	60,92 €	52,07 €	43,85 €	37,98 €	33,59 €	30,17 €
3	251,12 €	126,82 €	85,40 €	61,18 €	52,28 €	44,01 €	38,11 €	33,69 €	30,25 €

Table 26 - Ecological_cost of the AI Hypothesis as a function of Tot_em and standard deviation (Lognormal distribution)

Hypothesis AI - R O I - Eco_Cost (€/tCO2eq)

Average (mc/y)	0,42	0,85	1,27	1,80	2,12	2,54	2,97	3,39	3,81
				Total Natural Gas Leakage (Mmc)					
standard deviation (dmc/h)	**10**	**20**	**30**	**42,4**	**50**	**60**	**70**	**80**	**90**
0,6	463,25 €	232,72 €	165,48 €	129,83 €	117,91 €	107,85 €	101,58 €	97,63 €	95,17 €
0,8	404,09 €	193,53 €	131,23 €	97,10 €	85,08 €	74,21 €	66,68 €	61,18 €	57,02 €
1	371,04 €	173,66 €	115,18 €	83,06 €	71,67 €	61,30 €	54,04 €	48,68 €	44,56 €
1,2	349,61 €	161,53 €	105,84 €	75,28 €	64,45 €	54,60 €	47,69 €	42,58 €	38,65 €
1,4	334,42 €	153,28 €	99,69 €	70,32 €	59,94 €	50,49 €	43,88 €	38,99 €	35,24 €
1,6	322,98 €	147,27 €	95,30 €	66,87 €	56,83 €	47,71 €	41,33 €	36,62 €	33,01 €
1,8	314,00 €	142,66 €	92,00 €	64,31 €	54,55 €	45,68 €	39,49 €	34,93 €	31,44 €
2	306,71 €	138,99 €	89,41 €	62,33 €	52,79 €	44,14 €	38,10 €	33,66 €	30,26 €
2,2	300,66 €	135,99 €	87,31 €	60,75 €	51,39 €	42,92 €	37,01 €	32,66 €	29,34 €
2,4	295,53 €	133,48 €	85,57 €	59,44 €	50,25 €	41,92 €	36,12 €	31,85 €	28,59 €
2,6	291,11 €	131,35 €	84,11 €	58,35 €	49,29 €	41,09 €	35,38 €	31,18 €	27,98 €
2,8	287,25 €	129,51 €	82,85 €	57,42 €	48,47 €	40,39 €	34,75 €	30,62 €	27,46 €
3	283,85 €	127,90 €	81,75 €	56,61 €	47,77 €	39,78 €	34,22 €	30,13 €	27,01 €