COMPATIBILITY ASSESSMENT OF NON-STEEL METALLIC DISTRIBUTION GAS GRID MATERIALS WITH HYDROGEN

CANDHy

# D2.1

# Inventory of non-steel metallic materials of the natural gas distribution grid


| | |
|---|---|
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# Table of Content

# EXECUTIVE SUMMARY

WP2 of CANDHy project started with the analysis of the materials present in the natural gas distribution network of EU countries, including Ukraine and the UK. A total of 29 countries have been analysed, reporting an overall length of 2,471,198.91 km of natural gas distribution network.

For this network, not only the pipe materials present were analysed, to establish which materials should be tested in the experimental campaigns, but also other aspects such as the odorant used in the network, the nominal diameter, thickness and installation time of the pipes, the materials used in the accessories and the auxiliary elements installed in the network and the welding material. These aspects were examined in order to be able to determine the operating conditions of the gas grid materials.

To obtain all this information, with the highest level of detail, Redexis together with FHa, RINA and SIDSA developed a survey that was sent to several DSOs and National Gas Associations, along with GERG. The survey was sent to a total of 43 entities from several countries, and the information obtained represented the grid of the following countries: Austria, Belgium, Germany, Greece, Italy, Portugal, Slovakia, Spain and Ukraine.

For the first analysis of the grid, the pipe materials were divided into steel materials, non-steel metallic materials and non-metallic materials, in order to know how much of the network is built by each type. The results obtained were:

- 701,120.64 km of the grid are made of steel pipes.
- 49,405.92 km of the grid are made of non-steel metallic materials pipes.
- 1,154,873.55 km of the grid are made of non-metallic materials pipes.
- For 490,752 km the materials present in the grid are known, but not their individually length.
- For 75,046.80 km the pipe material is unknown.

Once the materials present in the current natural gas distribution grid were determined, the analysis focused on the aspects of the network made of metallic materials other than steel, which represent 2% of the total mentioned grid.

**Odorant used**

The non-steel metallic materials are exposed not only to natural gas but also to the odorant that is used. The most commonly odorants used are THT (Tetra-Hydro-Thiophene) and TBM (Tert-butyl-mercaptan).

**Length per diameter**

Pipe diameters have been obtained for 21% of the grid made of the collected non-steel metallic materials. Nominal diameters from 15 to 600 mm have been reported. In general, the most representative nominal diameter value is 300 mm, followed by 350 and 400 mm.

Copper pipes have smaller diameters, equal to or less than 125 mm, while iron pipes have higher diameters between 32 and 600 mm. For ductile cast iron pipes, the most representative diameter is 150 mm, followed by 100 mm and 200 mm.  The pipes for which the iron type was not specified present these same representative values with 100 mm diameter being the most used. Higher pipe diameters of dimensions 300, 350 and 350 mm are used for gray cast iron pipes.

**<u>Operating pressure</u>**

The values for the pipes operating pressure conditions have been obtained for 74% of the grid. The pressure ranges reported per material are the following:

| | Copper | Ductile cast iron | Gray cast iron |
|---|---|---|---|
| **16 ≥ MOP > 5 bar** | X | X | X |
| **8 ≥ MOP ≥ 4 bar** | | X | |
| **5 ≥ MOP > 0,4 bar** | | X | |
| **4 ≥ MOP ≥ 1 bar** | | X | X |
| **0,5 ≥ MOP > 0,04 bar** | X | X | X |
| **0,4 ≥ MOP > 0,05 bar** | X | X | X |
| **0,1 ≥ MOP ≥ 0,03 bar** | | X | X |
| **MOP ≤ 0,1 bar** | X | X | X |
| **MOP ≤ 0,05 bar** | X | X | X |
| **MOP ≤ 0,04 bar** | | X | X |

**<u>Thickness</u>**

The thickness has been provided for 3% of the grid. The data was given as a value or a range, including the maximum and minimum thickness for each nominal diameter. The values obtained per material were:

- For copper pipes:

<table>
<tr><th rowspan="2">Thickness (mm)</th><th colspan="9">Diameter (mm)</th></tr>
<tr><td>15</td><td>20</td><td>22</td><td>28</td><td>32</td><td>50</td><td>80</td><td>100</td><td>125</td></tr>
<tr><td>Minimum value</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1</td><td rowspan="2">1.2</td><td>1.2</td><td>1.2</td><td>1.2</td></tr>
<tr><td>Maximum value</td><td>1.5</td><td>1.5</td><td>2</td></tr>
</table>

- For ductile cast iron pipes:

<table>
<tr><th rowspan="2">Thickness (mm)</th><th colspan="11">Diameter (mm)</th></tr>
<tr><td>60</td><td>80</td><td>100</td><td>125</td><td>150</td><td>200</td><td>250</td><td>300</td><td>350</td><td>400</td><td>500</td></tr>
<tr><td>Minimum value</td><td rowspan="2">6</td><td>6</td><td>6</td><td>6</td><td>6</td><td>6.3</td><td>6.8</td><td>7.2</td><td rowspan="2">7.7</td><td>8.1</td><td rowspan="2">9</td></tr>
<tr><td>Maximum value</td><td>8.3</td><td>9</td><td>9.1</td><td>9.4</td><td>10.4</td><td>11.4</td><td>12.4</td><td>15</td></tr>
</table>

- For gray cast iron pipes:

<table>
<tr><th rowspan="2">Thickness (mm)</th><th colspan="8">Diameter (mm)</th></tr>
<tr><td>40</td><td>80</td><td>100</td><td>150</td><td>200</td><td>300</td><td>400</td><td>600</td></tr>
<tr><td>Minimum value</td><td rowspan="2">6.8</td><td rowspan="2">9</td><td rowspan="2">9</td><td rowspan="2">10</td><td rowspan="2">11</td><td>7.2</td><td rowspan="2">14.5</td><td rowspan="2">17</td></tr>
<tr><td>Maximum value</td><td>13</td></tr>
</table>

**Installation years**

Cast iron pipes (both, ductile and gray) were installed much earlier than copper pipes, however, at the present time, cast iron pipes have been removed from the grid and only copper pipes are still in use.

| Material | Initial year | Final year |
|---|---|---|
| Copper | 1977 | Up to now |
| Ductile cast iron | 1939 | 2020 |
| Gray cast iron | 1939 | 2015 |

Some other conclusions that can be extracted from the survey regarding the installation years are the following:

- Most part of the copper grid has been installed recently, particularly, between 2011 and 2020.
- The ductile cast iron grid is slightly older, as most of the existing network was installed between 2001 and 2010.
- In contrast, the current network made of gray cast iron pipes is much obsolete, since much of it was built between 1961 and 1970.
- Most of the unspecified iron pipe network was built a decade after the gray cast iron pipes, between 1971 and 1980.

**Accessories and auxiliary elements**

The accessories and auxiliary elements have been constructed with more non-steel metallic materials than the pipes. The most commonly used material is ductile cast iron, followed by gray cast iron and brass. The materials used for the accessories and auxiliary elements in the natural gas distribution grid are listed below.

| **Accessories and auxiliary elements** | | **Material** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Aluminum | Brass | Copper | Ductile cast iron | Gray cast iron | Lead | Zamak | Bronze |
| Valves | | | X | | X | X | X | | X |
| Pipe connector types | Elbows | | X | X | X | X | | | |
| | Tees | | X | X | X | X | | | |
| | Reducers | | X | X | X | X | | | |
| | Unions | | X | X | X | X | | | |
| | Couplings | | X | X | X | X | | | |
| | Crosses | | X | | X | X | | | |
| | Flanges | | | | X | X | | | |
| | Caps | | X | | X | X | | | |
| | Swage | | X | | X | | | | |
| | Nipples | | X | | X | X | | | |
| | Plugs | | | | X | | | | |
| | Bushings | | X | | X | | | | |
| | Adapters | | X | | | | | | |
| Regulator | | X | X | | X | X | | X | |
| Flow meters | | X | | X | X | X | | | |
| Filter (body) | | X | | | X | X | | | |

## Welding material

Not enough information was obtained regarding this aspect.

# 1. INTRODUCTION AND OBJECTIVES

As natural gas transmission networks are the ones through which natural gas is transported over long distances and between countries, they are more standardised than distribution networks. This is also due to the difference in the number of TSOs (Transport System Operators) and DSOs (Distribution System Operators) in a country, as some countries have only one TSO, while they may have several DSOs; in addition, the gas infrastructure is highly variable from one DSO to another, not only in terms of grid length, but also in terms of the number of connected customers, the age of the network and the installation procedures employed. Moreover, research on hydrogen compatibility with natural gas networks' materials has also been more focused on the transmission network.

In this context, the CANDHy project was conceived to analyse the compatibility of non-steel metallic materials present in gas distribution networks, with the aim of being able to assess their integrity when these materials are exposed to various natural gas and hydrogen blends, and to 100 vol% hydrogen, in order to enable the hydrogen injection into the natural gas grids.

This deliverable is framed within the task dedicated to the data collection on the current structure of the European natural gas distribution networks and aims to identify those non-steel metallic materials present in these grids. Specifically, the following aspects of these networks were analysed:

- Materials from which the installed pipes are made.
- Type of odorant used.
- Length of the grid according to nominal diameter and material.
- Operating pressure.
- Pipe thickness, depending on nominal diameter and material.
- Time period in which each material was used in the construction of the grid.
- Materials from which the accessories and auxiliary elements are made.
- Welding materials.

In order to gather as much information as possible on the structure of the European natural gas distribution networks, as much of it is not public, a survey has been developed to share with the most relevant stakeholders, DSOs and National Gas Associations.

The information collected was analysed and will serve as a basis for the tasks dedicated to the definition of the experimental campaign, in which the materials identified will be tested under different mixtures of hydrogen and natural gas, in their normal operating conditions.

# 2. ANALYSIS OF THE EXISTING NATURAL GAS DISTRIBUTION GRID

The first aspect that defines the structure of the European natural gas network is its overall length. This value will not only allow to determine the size of the distribution network in the analysed countries, but also how representative the obtained information is.

The results analysed comprises the materials present in the grids of all EU countries, plus Ukraine and the United Kingdom, making a total of 29 countries having been analysed. Information was provided or obtained from the public domain. The overall length of the natural gas distribution network for these countries is about 2,471,198 km and it is distributed, by country, as follows (Table 1):

Table 1. Total length of the natural gas distribution network by country

| Country | Length (km) | |
|---|---|---|
| Austria | 44,500 | [1] |
| Belgium | 75,547 | [2] |
| Bulgaria | 5,461 | [3] |
| Croatia | 19,981 | [4] |
| Cyprus | 0 | [5] |
| Czech Republic | 74,973 | [6] |
| Denmark | 18,414 | [7] |
| Estonia | 2,134 | [8] |
| Finland | 1,786 | [9] |
| France | 214,117 | [10] |
| Germany | 562,447 | [11] |
| Greece | * | |
| Hungary | 85,042 | [12] |
| Ireland | 12,140 | [13] |
| Italy | 272,320 | [14] |
| Latvia | 5,442 | [15] |
| Lithuania | 9,644 | [16] |
| Luxembourg | 3,155 | [17] |
| Malta | 0 | [18] |
| Poland | 195,179 | [19] |
| Portugal | 19,535.42 | |
| Romania | 43,563 | [20] |
| Slovakia | * | |
| Slovenia | 5,030 | [21] |
| Spain | 81,530.75 | |
| Sweeden | 2,620 | [22] |
| The Netherlands | 125,348 | [23] |
| United Kingdom | 265,000 | [24] |
| Ukraine | * | |

* Values not presented to keep confidentially of the data obtained by the survey, but they are considered in the overall length.

The public information that was found on the networks of the analysed countries only comprises the length of their network and the materials present, but not its proportionality and all the aspects mentioned in Section 1, which are of interest for the experimental campaign. Although there are some exceptions which will be seen in Section 3, where all the public information obtained will be presented. Due to the level of detail that needs to be known about the materials present in the natural gas distribution networks, which is not only about the materials used, but also about its form and the quantity, a survey was prepared and sent to different stakeholders. The intention of this survey was to improve the level of detail of the information obtained from the analysis of the public reports provided by DSOs and National, European and Global bodies.

## 2.1 Survey sent to the stakeholders

This survey was prepared by Redexis taking into consideration the characteristics of the natural gas distribution networks, together with FHa, RINA and SIDSA to gain a deeper understanding on the aspects that define the natural gas distribution network of each country. It was shared by the partners involved, along with GERG, to a total of 43 entities, namely DSOs and National Gas Associations.

These entities were from the following countries: Austria, Belgium, Bulgaria, Czech Republic, Denmark, France, Germany, Greece, Ireland, Italy, Poland, Portugal, Romania, Slovakia, Spain, Switzerland, The Netherlands, Ukraine and United Kingdom, as they are the countries with the longest network length. However, the surveys received provide information only from the following countries: Austria, Belgium, Germany, Greece, Italy, Portugal, Slovakia, Spain and Ukraine.

The survey consisted of several spreadsheets with tables to be filled in with the required information, including one with instructions to make it easier to complete the survey. The first thing requested was the total length of the grid for each type of material (Figure 1), to determine the percentage of each type of material, including steel material, metallic materials other than steel, and non-metallic materials; followed by the type of odorant used, which standard/code/norm established it and the period of time each odorant has been used (Figure 2).

| PIPELINE (global) | |
|---|---|
| Table 1 - Piping materials used in your distribution network | |
| Material | Length (km) depending on material |
| Steel materials (API 5L Gr. B, etc.) | |
| Metallic materials other than steel (Cast iron, etc.) | |
| Non-metallic materials (Poliethilene, Polyamide, etc.) | |
| Total length of the whole grid | |

Figure 1. Table for requesting the grid length per type of material

| PIPELINE (global) | | | |
|---|---|---|---|
| Table 2 - Odorant used in the natural gas network | | | |
| Type of odorant used | Odorant Standard / Code / Norm | Period of use (in years) | |
| | | Start year | End year |
| THT (Tetra-Hydro-Thiophene) | | | |
| TBM (Tert-butyl-Mercaptan) | | | |
| Mercaptanes (to be specified) | | | |
| Acrylates (to be specified) | | | |
| Mixtures (to be specified) | | | |
| Other (to be specified) | | | |

Figure 2. Table for requesting data about the odorant used

Once the length by type of material has been obtained, it was requested to specify which non-steel metallic materials are in the network, according to the length and the diameter of the pipe (Figure 3).

| PIPELINE (non-steel metallic materials) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Length (km) depending on material and nominal diameter | | | | | | | | | | |
| Material & Standard/Type/Grade | ND (mm) / NPS (inch) | 8 mm<br>0,25" | 20 mm<br>0,75" | 40 mm<br>1,5" | 80 mm<br>3" | 115 mm<br>4,5" | 200 mm<br>8" | 350 mm<br>14" | 500 mm<br>20" | Other (to be specified) |
| Aluminium | Standard / Type / Grade | | | | | | | | | |
| Brass | Standard / Type / Grade | | | | | | | | | |
| Copper | Standard / Type / Grade | | | | | | | | | |
| Ductile Cast iron | Standard / Alloy Type (GJL or GJS) / Grade | | | | | | | | | |
| Gray Cast iron | Standard / Alloy Type (GJL or GJS) / Grade | | | | | | | | | |
| Lead | Standard / Type / Grade | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | |

Figure 3. Table for requesting the pipe length and its diameter per material

The time period used for each material in the construction of the grid was the next aspect requested, to obtain information about the age of the network. This information was required by initial and final year of installation (Figure 4), and by installed length in a given decade (Figure 5), to study the growth of the grid over time according to the material.

| PIPELINE (non-steel metallic materials) | | |
|---|---|---|
| Table 1 - Range of years in which each material was installed in the distribution grid | | |
| Material | Initial year | Final year |
| Aluminium | | |
| Brass | | |
| Copper | | |
| Ductile Cast iron | | |
| Gray Cast iron | | |
| Lead | | |
| Other (to be specified) | | |
| Other (to be specified) | | |
| Other (to be specified) | | |
| Other (to be specified) | | |
| Other (to be specified) | | |
| Other (to be specified) | | |

Figure 4. Table for requesting the initial and final year of use of the materials

| PIPELINE (non-steel metallic materials) |
|---|
| Table 2 - Length (km) or average length (%) depending on the period of installation and material used |

| Material | Before 1950 | 1951 to 1960 | 1961 to 1970 | 1971 to 1980 | 1981 to 1990 | 1991 to 2000 | 2001 to 2010 | 2011 to 2020 | 2021 to 2023 |
|---|---|---|---|---|---|---|---|---|---|
| Aluminium | | | | | | | | | |
| Brass | | | | | | | | | |
| Copper | | | | | | | | | |
| Ductile Cast iron | | | | | | | | | |
| Gray Cast iron | | | | | | | | | |
| Lead | | | | | | | | | |
| Other (to be specified) | | | | | | | | | |
| Other (to be specified) | | | | | | | | | |
| Other (to be specified) | | | | | | | | | |
| Other (to be specified) | | | | | | | | | |
| Other (to be specified) | | | | | | | | | |
| Other (to be specified) | | | | | | | | | |

Figure 5. Length of network installed per decade and per material

The last aspect requested regarding the pipes was the welding material and the welding technique used in their construction (Figure 6).

| PIPELINE (non-steel metallic materials) |
|---|
| Length (km) or average lenght (%) of pipeline welded with specific welding material/technique |

| Pipe Material & Welding standard & Welding procedure/technique | | Welding material | To be specified | To be specified | To be specified |
|---|---|---|---|---|---|
| Aluminium | Welding standard | Welding procedure / technique | | | |
| Brass | Welding standard | Welding procedure / technique | | | |
| Copper | Welding standard | Welding procedure / technique | | | |
| Ductile Cast iron | Welding standard | Welding procedure / technique | | | |
| Gray Cast iron | Welding standard | Welding procedure / technique | | | |
| Lead | Welding standard | Welding procedure / technique | | | |
| Other (to be specified) | Welding standard | Welding procedure / technique | | | |
| Other (to be specified) | Welding standard | Welding procedure / technique | | | |
| Other (to be specified) | Welding standard | Welding procedure / technique | | | |
| Other (to be specified) | Welding standard | Welding procedure / technique | | | |
| Other (to be specified) | Welding standard | Welding procedure / technique | | | |
| Other (to be specified) | Welding standard | Welding procedure / technique | | | |

Figure 6. Welding material and technique per pipe material and length

Finally, it was required to specify which non-steel metallic materials, the accessories and auxiliary elements installed in the grid are made of (Figure 7).

| ACCESORIES and AUXILIAR ELEMENTS (non-steel metallic materials) |
| --- |
| Materials (yes or no; number of components) used for components, accessories and auxiliar elements |

| Material | Valves | Pipe connector types | | | | | | | | | | | | | | Regulator | Flow meters | Filter (body) | Other (to be specified) |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | | Elbows | Tees | Reducers | Unions | Couplings | Crosses | Flanges | Caps | Swage | Nipples | Plugs | Bushings | Adapters | Outlets | | | | |
| Aluminium | | | | | | | | | | | | | | | | | | | |
| Brass | | | | | | | | | | | | | | | | | | | |
| Copper | | | | | | | | | | | | | | | | | | | |
| Ductile Cast iron | | | | | | | | | | | | | | | | | | | |
| Gray Cast iron | | | | | | | | | | | | | | | | | | | |
| Lead | | | | | | | | | | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | | | | | | | | | | |
| Other (to be specified) | | | | | | | | | | | | | | | | | | | |

Figure 7. Accessories and auxiliary elements per material

# 3. STRUCTURE OF THE EXISTING NATURAL GAS DISTRIBUTION GRID

Following the analysis of public information and surveys, the data collected, from the 29 studied countries, were as follows.

## 3.1 Grid overview

A total of 2,471,198.91 km has been analysed. The materials used in the installation of this pipe grid were divided into steel materials, metallic materials other than steel and non-metallic materials, as it is represented in Figure 8. It was established that:

- 28% of the pipes are made of steel.
- 2% are made of a metallic material other than steel. This represents 49,406 km of the grid.
- 47% are made of non-metallic materials.
- In 20% of the grid, the materials present are known but not the distribution length of each material. This represents 490,752 km of the grid, of which, at least, 488,618 km (99%) are non-metallic materials or steel.
- 3% of the grid is unknown regarding which materials are present. This length corresponds to Bulgaria, Croatia, Finland, Luxembourg and Slovenia grid, and some km of the grid from Austria (5,322 km), Czech Republic (9,973 km), Germany (6,222 km), Romania (17,988 km) and The Netherlands (128 km).

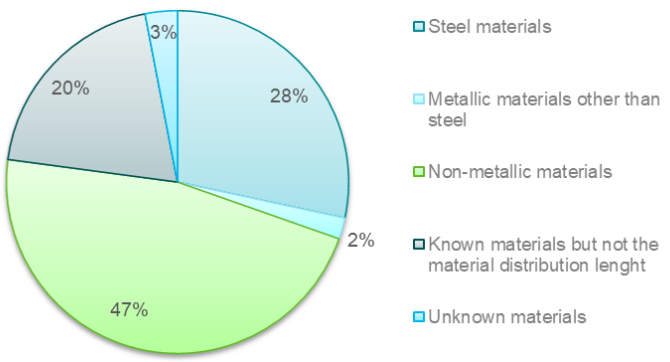


Figure 8. Type of materials present in the natural gas distribution grid

### 3.1.1 Analysis per countries

As for some countries, the distribution length per material is unknown, but not the materials present in the grid. The materials for which data has been found and obtained to be present in the network are shown below (Table 2).

Table 2. Materials present in the grid per country

| Country | Materials | | | | |
|---|---|---|---|---|---|
| | Steel | Copper | Cast iron | Plastic | |
| Austria | X | | X | X | [25] |
| Belgium | X | | X | X | [2] |
| Czech Republic | X | | | X | [26] |
| Denmark | X | | | X | [27] |
| Estonia | X | X | X | X | [28] |
| France | X | X | X | X | [29] |
| Germany | X | | X | X | [11] |
| Greece | Non-steel metallic materials have been reported. * | | | | |
| Hungary | X | | | X | [12] |
| Ireland | | | | X | [13] |
| Italy | X | | X | X | [14] |
| Latvia | X | | | X | [15] |
| Lithuania | X | | | X | [16] |
| Poland | X | | | X | [30] |
| Portugal | X | X | | X | |
| Romania | X | | | X | [31] |
| Slovakia | No metallic materials other than steel have been reported. * | | | | |
| Spain | X | X | X | X | |
| Sweeden | X | | | X | [32] |
| The Netherlands | X | | X | X | [23] |
| Ukraine | Non-steel metallic materials have been reported. * | | | | |
| United Kingdom | X | | X | X | [24] |
| *For these countries, pipe materials have been specified, but are not indicated in order to maintain confidentiality of the data. | | | | | |

- **Austria:** the Austrian network has a length of 44,500 km, of which, at least, 1,311.4 km are from non-steel metallic materials, particularly, ductile cast iron (1,311 km) and gray cast iron (0.4 km). [25]
- **Belgium:** has a grid with a length of 75,547 km, of which 15 km are from ductile cast iron and 251 km from gray cast iron. [2]
- **Bulgaria:** only information about their total length of the grid was found. [3]
- **Croatia:** only information about their total length of the grid was found. [4]
- **Cyprus:** without distribution grid. [5]
- **Czech Republic:** has 74.973 km of grid. No presence of non-steel metallic materials was reported, only steel and polyethylene (PE), but there are 9,973 km of which the material pipe is unknown. [26]

- **Denmark:** metallic materials other than steel were not reported in its 18,414 km of grid. [27]
- **Estonia:** it could have copper and ductile cast iron in its grid, but its distributed length is unknown. [28]
- **Finland:** only the total length of the grid (1,786 km) has been reported. [9]
- **France:** 4,282 km from ductile cast iron and less than 2,141.17 km of copper, from 214,117 km of its grid. [29]
- **Germany:** the Germany gas distribution grid has a total length of 562,447 km, of which 7,312 km correspond to ductile cast iron pipes and 1,125 km, to gray cast iron pipes. [11]
- **Greece:** metallic materials other than steel were reported.
- **Hungary:** its grid has a length of 85,042 km, with no presence of non-steel metallic materials. [12]
- **Ireland:** only PE have been reported in its 12,140 km of grid. [13]
- **Italy:** 2,060 km correspond to gray cast iron pipes, 1,011 km to ductile cast iron and other 715 km were reported as non-steel metallic materials. [14]
- **Latvia:** no presence of non-steel metallic materials was reported in its 5,442 km of grid. [15]
- **Lithuania:** no presence of non-steel metallic materials was reported in its 9,644 km of grid. [16]
- **Luxembourg:** only information about their total length of the grid was found. [17]
- **Malta:** without distribution grid. [18].
- **Poland:** no presence of metallic materials other than steel was reported in its 195,179 km of grid. [30]
- **Portugal:** presence of copper pipes was reported.
- **Romania:** from Delgaz, one of its DSOs, it was obtained that non-steel metallic materials are present in its 25,575 km of grid, but no information, from the other DSO, was found. [31]
- **Slovakia:** metallic materials other than steel were not reported in its grid.
- **Slovenia:** only information about their total length of the grid was found. [21]
- **Spain:** 1,261 km of non-steel metallic materials were reported, 76 km from copper, 1,182 km from ductile cast iron and 2.6 km from gray cast iron.
- **Sweeden:** only PE and steel were reported in its 2,620 km of grid. [32]
- **The Netherlands:** from 125,437 km, 2,747 km correspond to gray cast iron pipes and 1,469 km to ductile cast iron. [23]
- **United Kingdom:** 9,400 km of iron were reported, but the type was not specified, although spun iron and ductile iron were mentioned. [24]

- **Ukraine:** presence of non-steel metallic materials was reported.

Taking into consideration these numbers, if we represent only the non-steel metallic materials present in the grid, this represent 49,406 km of the total length of the grid, hence Figure 8 becomes Figure 9, and the following is established:

- 5% of this length correspond to copper pipes (2,222 km).
- 95% of the non-steel metallic materials pipes are made of iron (47,183.55 km). 34% are made of ductile cast iron, 41% of gray cast iron and 20% of an iron type that has not been specified.

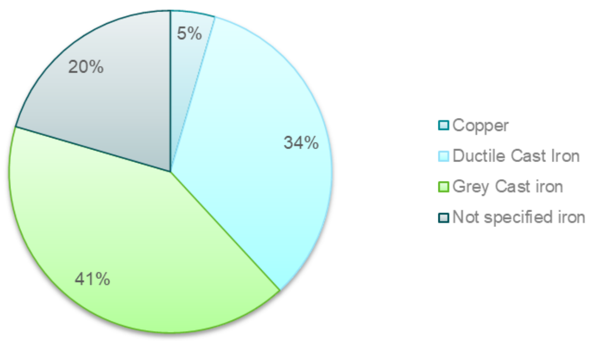


Figure 9. Type of non-steel metallic materials present in the natural gas distribution grid

## 3.2 Odorant used

Information about the odorant used in Austria, Belgium, Greece, Italy, Portugal, Slovakia, Spain and Ukraine was reported, being THT (Tetra-Hydro-Thiophene) and TBM (Tert-butyl-mercaptan) the most used odorants.

## 3.3 Length per diameter

The information regarding the pipe's diameter per length and material, represents 8,782 km of the total 49,405.52 km, which represent 21% of the grid which is made of a metallic material other than steel.

The reported nominal diameters range from 15 mm to 600 mm. The pipe length according to the various diameters is very wide and is shown in Figure 10.

In general:

- The most representative nominal diameter value is 300 mm, which represents a 19% of the values collected; then 350 and 400 mm, with a 17%, and then 150 mm, with a 12%.

- 12.98% of the values correspond to nominal diameters equal to or less than 100 mm.
- 48.5% of the values correspond to nominal diameters between 115 and 300 mm, both included.
- 36.77% of the values correspond to nominal diameters between 350 and 450 mm, both included.
- 1.76% of the values correspond to nominal diameters equal to or bigger than 500 mm.

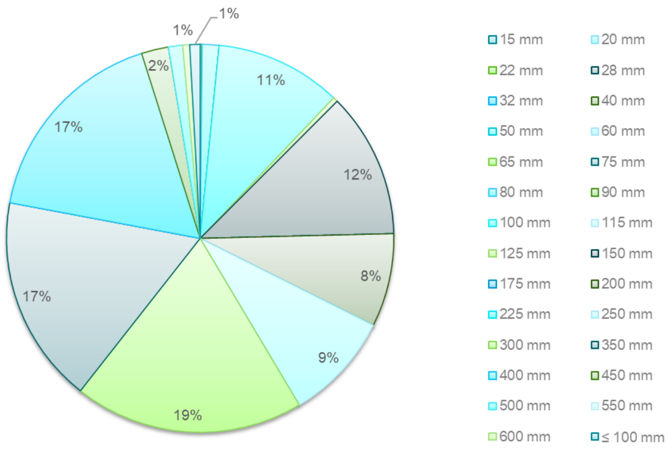


Figure 10. Distribution of nominal diameters per length

### 3.3.1 Length per diameter and material

If this information was analysed by type of material, the values would be as follows.

#### 3.3.1.1 Copper

The data collected regarding copper pipes correspond to 81.24 km of 2,222.45 km. The nominal diameters that have been reported are 15, 20, 22 (length not specified), 28 (length not specified), 32, 50, 80, 100 and 125 mm (Figure 11).

For 95% of them it was only specified that the diameter was less than 100 mm, without specifying the exact value. Without considering these km, the most representative nominal diameter value is 32 mm, followed by 80 mm.

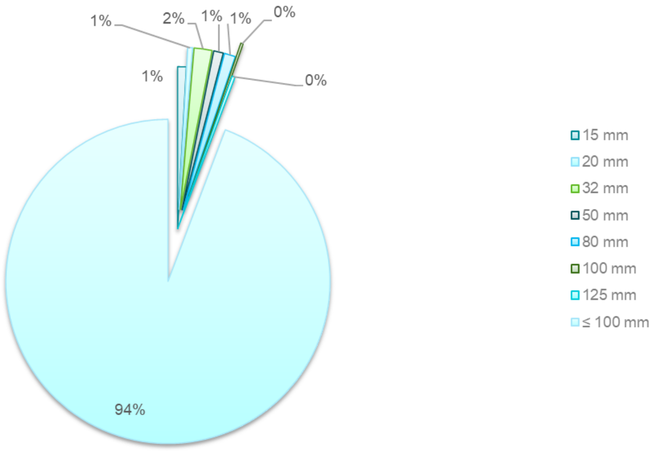


Figure 11. Distribution of the nominal diameter per length of copper pipes

#### 3.3.1.2 Ductile Cast Iron

For Ductile Cast Iron, data about 2,463 km were reported, representing 14% of this material's grid.

The reported nominal diameters were between 40 to 600 mm, which are represented in Figure 12.

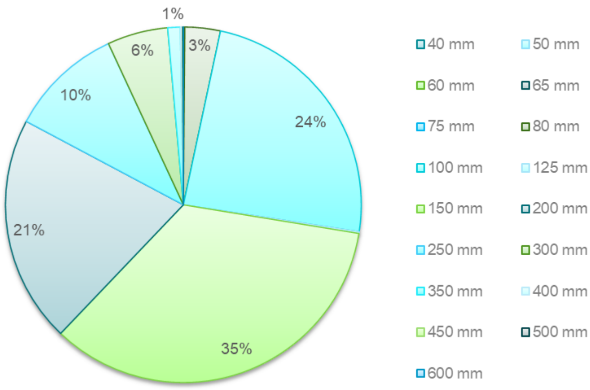


Figure 12. Distribution of the nominal diameter per length of ductile cast iron pipes

From the figure above it can be seen that:

- The most representative nominal diameter value is 150 mm, which represents 34.54% of the values collected; then 100 mm, representing 24.07%, and then 200 mm, representing 20.66%.
- 27.42% of the values correspond to nominal diameters equal to or less than 100 mm.
- 71.18% of the values correspond to nominal diameters between 115 and 300 mm, both included.
- 1.35% of the values correspond to nominal diameters between 350 and 450 mm, both included.

* 0.06% of the values correspond to nominal diameters equal to or bigger than 500 mm.

#### 3.3.1.3 Gray Cast Iron

Nominal diameters of 5,599.25 km of the total of 20,446.68 km of gray cast iron pipes analysed were reported, with values between 32 to 600 mm represented in Figure 13.

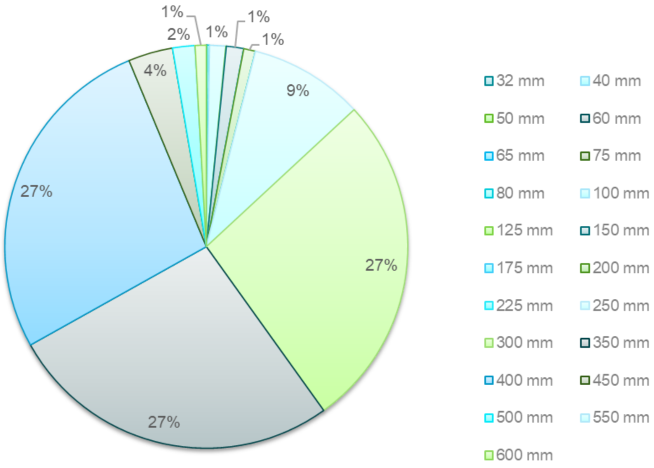


Figure 13. Distribution of the nominal diameter per length of gray cast iron pipes

* The most representative nominal diameters are 300, 350 and 400 mm, which represent almost each one 27%; then a nominal diameter of 250 mm, representing 9.18%.
* 1.54% of the values correspond to nominal diameters equal to or less than 100 mm.
* 38.56% of the values correspond to nominal diameters between 115 and 300 mm, both included.
* 57.21% of the values correspond to nominal diameters between 350 and 450 mm, both included.
* 2.69% of the values correspond to nominal diameters equal to or bigger than 500 mm.

#### 3.3.1.4 Not specified iron

Of the 10,115.25 km for which the iron type was not specified, information on the nominal diameter was provided for 715,25 km of them. The nominal diameters that were reported were from 40 to 600 mm (Figure 14).

* The most representative nominal diameter is 100 mm which represent a 37.62%; then 150 mm, with a 20.16%, and then 200 mm, with a 17,92%.
* 42.87% of the values correspond to nominal diameters equal to or less than 100 mm.
* 53.72% of the values correspond to nominal diameters between 115 and 300 mm, both included.

- 2.9% of the values correspond to nominal diameters between 350 and 450 mm, both included.
- 0.51% of the values correspond to nominal diameters equal to or bigger than 500 mm.

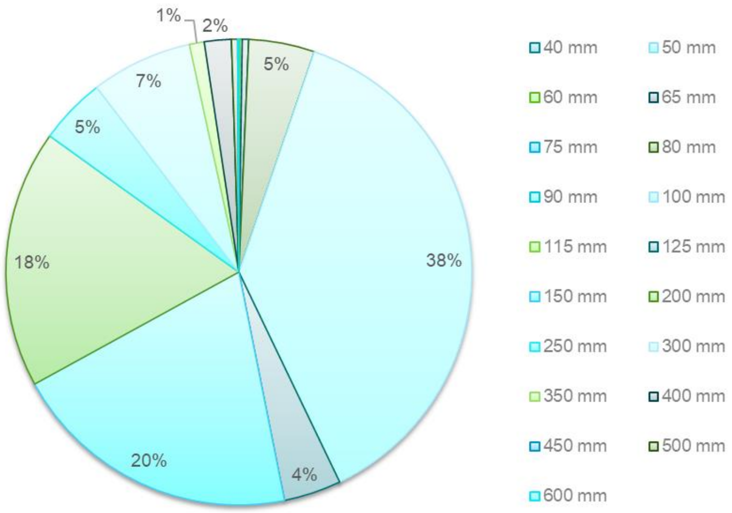


Figure 14. Distribution of the nominal diameter per length of iron pipes

## 3.4 Operating pressure

Regarding this aspect, the information represents 30,700 km of the grid, representing 74% of the grid which is made of a metallic material other than steel. The pressure ranges reported are as follow:

- 16 ≥ MOP > 5 bar
- 8 ≥ MOP ≥ 4 bar
- 5 ≥ MOP > 0,4 bar
- 4 ≥ MOP ≥ 1 bar
- 0,5 ≥ MOP > 0,04 bar
- 0,4 ≥ MOP > 0,05 bar
- 0,1 ≥ MOP ≥ 0,03 bar
- MOP ≤ 0,05 bar
- MOP ≤ 0,04 bar
- MOP ≤ 0,1 bar

### 3.4.1 Copper

For copper pipes, the pressure ranges are:

- 16 ≥ MOP > 5 bar
- 0,5 ≥ MOP > 0,04 bar
- 0,4 ≥ MOP > 0,05 bar
- MOP ≤ 0,1 bar
- MOP ≤ 0,05 bar

### 3.4.2 Ductile cast iron

For ductile cast iron, all the pressure ranges mentioned in section 3.4 apply to this material.

### 3.4.3 Gray cast iron

Gray cast iron pipes are operated in these pressure ranges:

- 16 ≥ MOP > 5 bar
- 4 ≥ MOP ≥ 1 bar
- 0,5 ≥ MOP > 0,04 bar
- 0,4 ≥ MOP > 0,05 bar
- 0,1 ≥ MOP ≥ 0,03 bar
- MOP ≤ 0,1 bar
- MOP ≤ 0,05 bar
- MOP ≤ 0,04 bar

## 3.5 Thickness

The data obtained on the pipe thickness represent 1,277 km of the grid, representing 3% of the network reported to be made of a metallic material other than steel. For each nominal diameter, it is possible to have a thickness value range or only one value, depending on the information provided.

### 3.5.1 Copper

For copper pipes, with a nominal diameter equal to or less than 32 mm, the thickness reported was 1 mm. This value is increased to 1.2 mm for 50 mm diameters. For diameters between 80 and 125 mm, thickness ranges from 1.2 to 1.5 or 2 mm were mentioned (Table 3).

Table 3. Thickness per diameter for copper pipes

| Thickness (mm) | Diameter (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 15 | 20 | 22 | 28 | 32 | 50 | 80 | 100 | 125 |
| Minimum value | 1 | 1 | 1 | 1 | 1 | 1.2 | 1.2 | 1.2 | 1.2 |
| Maximum value | | | | | | | 1.5 | 1.5 | 2 |

### 3.5.2 Ductile cast iron

Regarding ductile cast iron pipes, the minimum thickness value that was reported for 60 to 150 mm diameters is 6 mm, while the maximum thickness value goes from 8.3 to 9.4 mm as the diameter increases. For diameters from 200 to 400 mm, the minimum thickness value increases from 6.3 to 8.1 mm, and the maximum, from 10.4 to 15 mm, with the exception of 350 mm where only a thickness of 7.7 mm was reported. The same happens for a 500 mm diameter, where the thickness mentioned was 9 mm (Table 4).

Table 4. Thickness per diameter for ductile cast iron

| Thickness (mm) | Diameter (mm) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 60 | 80 | 100 | 125 | 150 | 200 | 250 | 300 | 350 | 400 | 500 |
| Minimum value | 6 | 6 | 6 | 6 | 6 | 6.3 | 6.8 | 7.2 | 7.7 | 8.1 | 9 |
| Maximum value | | 8.3 | 9 | 9.1 | 9.4 | 10.4 | 11.4 | 12.4 | | 15 | |

### 3.5.3 Gray cast iron

For gray cast iron pipes, only for a 300 mm diameter pipe a thickness range was given, from 7.2 to 13 mm. For the rest of the values, the thickness goes from 6.8 mm for a diameter of 40 mm, to 17 mm for a diameter of 600 mm, with diameters of 80 and 100 mm having the same thickness value of 9 mm (Table 5).

Table 5. Thickness per diameter for gray cast iron

| Thickness (mm) | Diameter (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 40 | 80 | 100 | 150 | 200 | 300 | 400 | 600 |
| Minimum value | 6.8 | 9 | 9 | 10 | 11 | 7.2 | 14.5 | 17 |
| Maximum value | | | | | | 13 | | |

## 3.6 Installation years

The start and end year of installation of each particular material are (Table 6):

Table 6. Range of years in which each material was installed in the distribution grid

| Material | Initial year | Final year |
|---|---|---|
| Copper | 1977 | Up to now |
| Ductile cast iron | 1939 | 2020 |
| Gray cast iron | 1939 | 2015 |

The grid growth by length and as a function of the installation decade is shown below (Figure 15), it was determined that the years 2000 to 2010 saw the highest growth of the network using non-steel metallic materials, followed by the decade from 1991 to 2000. These data correspond to 19,567.89 km of the non-steel metallic material grid, representing 39.6% of the total grid made of these materials.

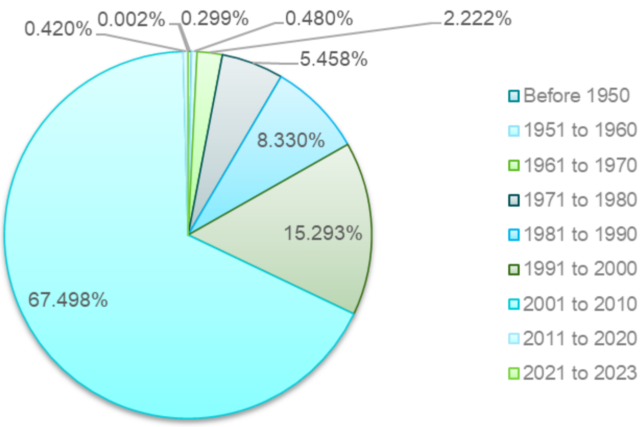


Figure 15. Grid growth, by length, per decade of years of installation

This information may not be very representative, because based on the data analysed, it is possible that these materials were used more frequently in recent decades. The truth is that many pipes made of non-steel metallic materials were installed many years ago, and these have been substituted and replaced by other materials (mainly polyethylene) in maintenance operations to maintain the networks' integrity, which undermines this information and the corresponding analysis.

### 3.6.1 Copper

86.53% of the grid made of copper has been installed between 2011 and 2020, while in the decades 1990 to 2000 and 2001 to 2010, 5% of the grid was installed in each decade (Figure 16).

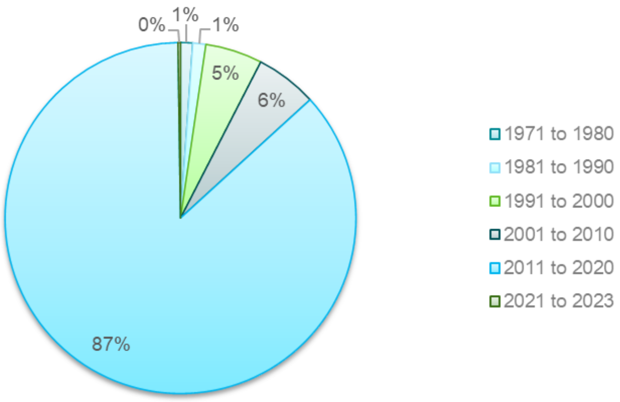


Figure 16. Copper pipes growth, by length, per decade of years of installation

### 3.6.2 Ductile cast iron

The strongest growth in ductile cast iron pipes took place in the decade from 2001 to 2010 (Figure 17), followed by the decade between 1991 and 2000.

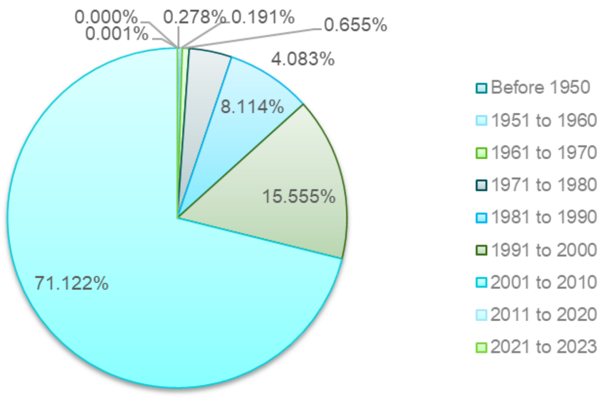


Figure 17. Ductile cast iron pipes growth, by length, per decade of years of installation

### 3.6.3 Gray cast iron

Unlike the previous materials, the largest growth of the gray cast iron network was before the 2000s, namely in the decade from 1961 to 1970 (Figure 18).

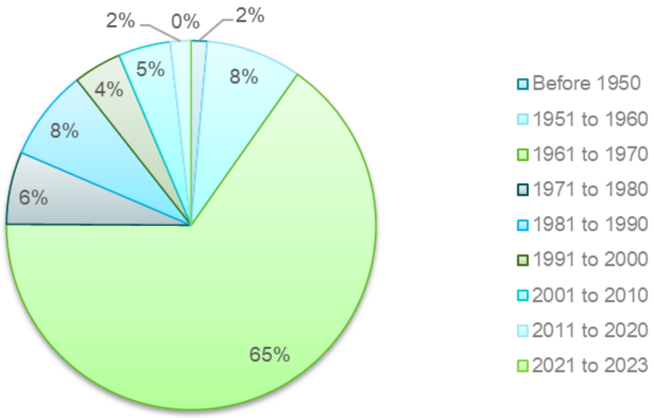


Figure 18. Gray cast iron pipes growth, by length, per decade of years of installation

### 3.6.4 Not specified iron

For pipes for which the iron type used in their installation was not specified, as in the previous case, the greatest growth in the cast iron network was before 2000, specifically in the decade from 1971 to 1980 (Figure 19).

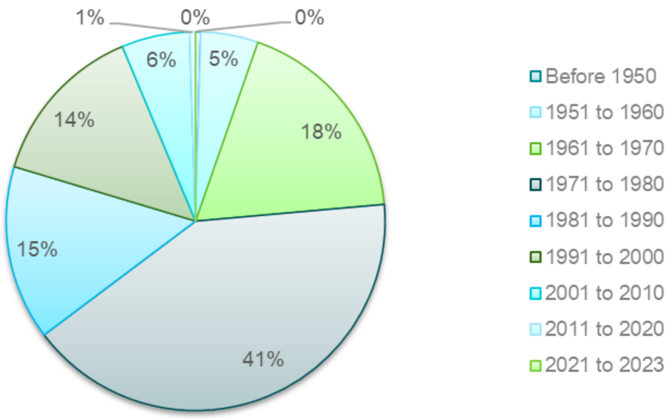


Figure 19. Iron pipes growth, by length, per decade of years of installation

## 3.7 Accessories and auxiliary elements

For accessories and auxiliary elements, the variety of non-steel metallic materials used in their construction is much wider than for the pipes in the natural gas distribution network, due to the fact that from 3 materials (copper, ductile cast iron and gray cast iron), the number of materials increases to 8 (aluminum, brass, copper, ductile cast iron, gray cast iron, lead, zamak and bronze) (Table 7).

Table 7. Accessories and auxiliary elements per material present in the natural gas distribution grid

| **Accessories and auxiliary elements** | | **Material** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Aluminum | Brass | Copper | Ductile cast iron | Gray cast iron | Lead | Zamak | Bronze |
| Valves | | | X | | X | X | X | | X |
| Pipe connector types | Elbows | | X | X | X | X | | | |
| | Tees | | X | X | X | X | | | |
| | Reducers | | X | X | X | X | | | |
| | Unions | | X | X | X | X | | | |
| | Couplings | | X | X | X | X | | | |
| | Crosses | | X | | X | X | | | |
| | Flanges | | | | X | X | | | |
| | Caps | | X | | X | X | | | |
| | Swage | | X | | X | | | | |
| | Nipples | | X | | X | X | | | |
| | Plugs | | | | X | | | | |
| | Bushings | | X | | X | | | | |
| | Adapters | | X | | | | | | |
| Regulator | | X | X | | X | X | | X | |
| Flow meters | | X | | X | X | X | | | |
| Filter (body) | | X | | | X | X | | | |

## 3.8 Welding material

In general, not enough information was reported on the welding material used for each type of material pipe, as this data is not usually collected by the DSOs. This information would need to be obtained from the pipe installation codes/standards/norms for every kind of material and its corresponding welding procedure.

# 4. CONCLUSIONS

A total of 29 countries have been analysed, representing an overall length of 2,471,198 km of natural gas distribution grid. These countries were Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweeden, The Netherlands, United Kingdom and Ukraine.

Of those 2,471,198.91 km:

- 701,120.64 km or 28% are made of steel pipes.
- 49,405.92 km or 2% are made of non-steel metallic materials. Reported materials of this type are copper (2,222 km), ductile cast iron (16,261 km), gray cast iron (20,447 km) and there are some pipe's kilometers (10,115 km) whose iron type is unknown.
- 1,154,873.55 km are made of non-metallic materials, representing 47% of the grid.
- For 20% of the grid, the materials present are known, but no its corresponding length. This represents 490,752 km.
- 3% of the grid is totally unknown regarding which materials are present in it.

Compared to copper, iron pipes are more present in the natural gas distribution grid. Considering only the non-steel metallic materials grid length, 94.8% of it is made of one type of iron. Among the types reported, the one that stands out the most is gray cast iron. Considering their presence per country, the use of iron pipes is more widespread than copper pipes, with at least 9 countries having iron pipes compared to 4 that have cooper pipes.

The results obtained for the aspects that are the subject of study in this deliverable, on the natural gas distribution grid made of non-steel metallic materials, are as follows.

**Odorant used**

The most used odorants are THT (Tetra-Hydro-Thiophene) and TBM (tert-butyl-mercaptan).

**Length per diameter**

Several nominal diameters were reported, but three stand out above the rest, the 300, 350 and 400 mm diameters.

Of the 8,858.79 km of pipe length for which their diameter was reported, 78.8% have a nominal diameter equal to or less than 350 mm. 1,521 km of pipelines have a diameter of 400 mm, while 200 km have a diameter of 450 mm, 105 km of 500 mm and 51 km of 600 mm.

The results per material for this aspect are as follows:

- All pipes made of copper have a nominal diameter equal to or less than 125 mm.

- The most representative nominal diameter for ductile cast iron pipes is 150 mm. For the testing campaign, only 0.27% (6.7 km) of the ductile cast iron pipes present a diameter equal to or higher than 400 mm.
- For gray cast iron pipes, the most significant diameters are 300, 350 and 400 mm. In contrast to the previous pipes, these pipes have a greater pipe length with a diameter equal to or greater than 400, 1,853 km (33% of the grid of this material).
- For pipes for which the iron type used in their construction is not specified, the most common diameter is 100 mm. 17 km of its grid, representing 2%, have a diameter equal to or higher than 400 mm.

**Operating pressure**

Several pressure ranges were reported for every material:

- Copper:
  - 16 ≥ MOP > 5 bar
  - MOP ≤ 0,05 bar
  - MOP ≤ 0,1 bar
  - 0,4 ≥ MOP > 0,05 bar
  - 0,5 ≥ MOP > 0,04 bar
- Ductile cast iron:
  - 16 ≥ MOP > 5 bar
  - 0,1 ≥ MOP ≥ 0,03 bar
  - MOP ≤ 0,04 bar
  - 8 ≥ MOP ≥ 4 bar
  - 0,4 ≥ MOP > 0,05 bar
  - 0,5 ≥ MOP > 0,04 bar
  - 5 ≥ MOP > 0,4 bar
  - MOP ≤ 0,05 bar
  - MOP ≤ 0,1 bar
  - 4 ≥ MOP ≥ 1 bar
- Gray cast iron:
  - 16 ≥ MOP > 5 bar
  - 0,4 ≥ MOP > 0,05 bar
  - 0,5 ≥ MOP > 0,04 bar
  - 4 ≥ MOP ≥ 1 bar
  - MOP ≤ 0,05 bar
  - MOP ≤ 0,1 bar
  - 0,1 ≥ MOP ≥ 0,03 bar
  - MOP ≤ 0,04 bar

**Thickness**

Depending on the material and the nominal diameter of the reported pipes, a thickness value range or single value was given. This aspect will also condition the vintage materials testing since the pipes are required to have a minimum thickness for the specimen's preparation.

- For copper, a maximum thickness of 2 mm for a diameter of 125 mm has been provided.
- Focusing on the higher diameters, a thickness of 9 mm has been provided for a 500 mm diameter ductile cast iron pipe, while for a diameter of 400 mm, the thickness range provided is between 8.1 and 15 mm.
- The thickness that was reported for a 400 and 600 mm diameter gray cast iron pipe is 14.5 and 17 mm, respectively.

**Installation years**

Cast iron pipes have been in use for the longest time, while copper started to be used later. Similarly, it is the case that cast iron is no longer used in the installation of new pipes, while copper is. Per decades, most gray cast iron pipes have been installed before the year 2000, in contrast to copper and ductile cast iron pipes which have been installed more between 2011 to 2020, and 2001 to 2010, respectively.

When carrying out the vintage materials test, the installation years is also an aspect to consider, as it is not the same for a pipe that has been installed for 10 years than for 50, as the latter would have been in operation for longer and could be more affected by hydrogen as it is more abraded.

**Accessories and auxiliary elements**

It has been reported accessories and auxiliary elements made of aluminum, brass, copper, ductile cast iron, gray cast iron, lead, zamak and bronze. The material most used for these accessories and auxiliary elements is ductile cast iron, followed by brass and gray cast iron. Lead, zamak and bronze are the less representative materials, with only one accessory/element made of each material.

**Welding material**

Not enough information was reported regarding this aspect.

## 5. ACKNOWLEDGEMENTS

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