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Summary

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Keywords: Heating, Residential Buildings, Hydrogen, Heat Pumps, Scenarios

JEL Classification: Q4, Q42, Q55

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The potential role of hydrogen towards a low-carbon residential heating in Italy

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Abstract

Buildings' heating represents an important share of the total energy consumption in Italy, and to reach the challenging decarbonization targets set by the EU by 2050, a combination of measures and technologies will be required. This working paper presents an analysis of different scenarios comparing the penetration of buildings' heating technologies for the residential sector in Italy. The objective of the research is to evaluate the potential contribution of different technologies, with a particular focus of the role that hydrogen may have to play, compared to other solutions, including heat pumps and renewable natural gas. The analysis compares the potential role of these technologies in reaching a decarbonized residential heating by 2050, by also discussing the main barriers and opportunities that lie ahead. The scenarios are defined starting from historical data of heating systems stock and sales, integrated with the know-how of experts of the sector to compare different pathways based on electrification or renewable gases. The results show that a combination of technologies will be in any case required in the heating sector, but also that other external factors will be of paramount importance, including the electricity decarbonization and energy efficiency measures on the building stock.

Keywords: heating, residential buildings, hydrogen, heat pumps, scenarios

1. Introduction

The European Union aims at reaching a decarbonized energy system by 2050, including a mid-term target of 55% net reduction of greenhouse gases emissions by 2030, compared to 1990 levels. This last target is the result of a raised ambition in comparison with a previous value of 40% reduction[1]. Such a challenging pathway, that is required to comply with the commitments of the Paris Agreement, will need to be based on the combination of different measures, including technologies for energy generation, distribution and final use, energy efficiency and demand management. Together with industry and transportation, buildings represent an important share of the final energy consumption in the EU. Due to weather conditions, buildings' heating represent the largest share of energy consumption in buildings in many countries.

This study presents a specific focus on residential buildings heating in Italy, by considering the historical evolution of different technologies in the last decade and comparing alternative scenarios to reach the decarbonization targets ahead. The main goal of this research study is to evaluate the potential role of hydrogen in the residential sector, in comparison with heat pumps and biomethane. In addition to considering historical market data at a national level, the scenario analysis will build on the expertise of Bosch, which is among the main players in buildings heating technologies.

Hydrogen is seeing a renewed interest in the last years, due to its potential role in supporting the decarbonization of the energy system, in particular in specific hard-to-abate sectors, including some transport segments and high-temperature industry applications. There is still a lack of consensus about the potential role of green and blue hydrogen in the energy transition[2], due to uncertainties related to the low energy efficiency of its supply chain and the potential cost reduction compared to other competing technologies. However, case studies on hydrogen applications are being tested worldwide in a wide range of final uses, and various scenarios are assessing the potential of hydrogen penetration in future energy systems for different countries. Some countries are also developing specific strategies related to hydrogen development, and in some cases they are also evaluating potential bi-lateral agreements to implement future low-carbon hydrogen trade routes.

[1] https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1599

[2] Noussan et al., 2021, The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective, Sustainability, https://www.mdpi.com/2071-1050/13/1/298

Considering the building sector, clean hydrogen is being considered as a low-carbon alternative in different EU countries, including the UK[3] and the Netherlands[4]. In the UK, there are currently several projects that are testing the transport of hydrogen into the gas network, either as a pure gas or blended with natural gas. In 2016, the H21[5] program has been launched, with the goal to demonstrate that the conversion of the existing gas grid, in the Leeds area, to carry 100% hydrogen is technically possible, safe and economically viable. The program, that is currently testing hydrogen in a demo building, has so far presented a conceptual design for converting the entire gas networks of the North of England (3,5 million metering points, representing 12,5% of the net UK population) to hydrogen between 2028 and 2035. In 2019, the British Government commissioned Hy4Heat[6], an innovation program to determine whether it is technically possible, safe, and convenient to replace natural gas (methane) with hydrogen in residential and commercial buildings and gas appliances, with the goal of determining whether to proceed to a community trial. The Hy4Heat program is now moving out of the laboratory and into the demonstration phase: in 2021, hydrogen boilers from Baxi Heating and Worcester Bosch have been installed in 'HyStreet' demonstration houses at DNV GL's Northumberland test site, as part of the H21 network innovation project. In Levenmouth (Scotland), the H100 Fife[7] project aims at bringing 100% renewable hydrogen into households by 2022, providing a zero-carbon fuel for heating and cooking. In the project's first phase, the network will heat around 300 local houses using clean gas produced by a dedicated electrolysis plant, powered by a nearby offshore wind turbine. Concerning blending, HyDeploy[8] project aims to prove that blending up to 20% of hydrogen with natural gas (by volume) is a safe and greener alternative to the gas we use now. The blended gas has already been successfully supplied to Keele University campus (100 homes) and, in 2021, it will be tested in a bigger area (in the town of Winlaton, for a total of about 650 homes). The UK has many characteristics that are very similar to Italy, considering the gas distribution network and the heating appliances, and for this reason it has to be observed with attention.

As showed in the HyDeploy project, another possibility for hydrogen to support the heating of residential buildings is through its blending in existing gas networks. Some TSOs, including SNAM[9], have tested the compliance of different levels of hydrogen blending in existing

[3] https://www.h21.green/
[4] https://waterstofkaart.missieh2.nl/
[5] https://www.h21.green/
[6] https://www.hy4heat.info/
[7] https://www.sgn.co.uk/H100Fife
[8] https://hydeploy.co.uk/
[9] https://www.snam.it/en/Media/news_events/2020/Snam_hydrogen_blend_doubled_in_Contursi_trial.html

transmission pipelines, up to 10% in volume. Such a level of low-carbon hydrogen blending, if applied to the current natural gas consumption in Italy, could ensure emission savings of up to 5 Mt of CO2eq per year[10]. However, a 10% blending rate in volume corresponds to a lower level when considering the energy content, and the lower energy density of hydrogen also means that the same pipelines have a lower capacity. Moreover, such rates of hydrogen blending may need an adaptation of different components, including meters, distribution networks and energy generators such as gas turbines, engines, cooking equipment and boilers. Although some manufacturers have already verified the maximum hydrogen blend levels for their equipment, more research is needed to verify the compliance of the existing infrastructure with different hydrogen blending levels. Moreover, additional actions may be needed to modify existing regulations and certification procedures[11].

Hydrogen use in Italy, which is the focus of this study, is currently being discussed in a roadmap, and preliminary guidelines have been published in November 2020[12]. The strategy is targeting hydrogen use in some transport and industry applications by 2030, together with a potential blend of low-carbon hydrogen in the natural gas grid. Applications on a long-term perspective, by 2050, include the use of hydrogen as a storage solution for electricity, as well as its use for residential and commercial buildings heating. Preliminary figures estimate potential targets of hydrogen share in final energy consumption up to 2% by 2030 and up to 20% by 2050. The strategy also estimates a required level of investments of around 10 billion €, with the aim of ensuring 8 Mt of CO_{2eq} of emission savings by 2030, with a target electrolysis capacity of 5 GW. Furthermore, the Italian government decided to include an important share of the budget of NRRP (National Recovery and Resilience Plan[13]), sent to EU Commission in April 2021, to the development of the clean hydrogen supply chain (3,64 bln €).

The interest of this study is to evaluate the potential role of hydrogen in support of the decarbonization of heating, considering the applications in Italian residential buildings, by comparing alternative future scenarios to highlight the contribution of different technologies. Specifically, the main goal of the project is to estimate the market penetration of hydrogen boilers and hydrogen-ready boilers. Thus, energy consumption will be a secondary result of the project, and its estimation will be used to compare the compliance of the heating systems stock per

[10] https://www.bakerhughes.com/sites/bakerhughes/files/2020-11/BakerHughes_Case_NovaLT12_H2_Snam_Istrana_A4-102720.pdf
[11] https://doi.org/10.1016/j.energy.2017.02.042
[12] https://www.mise.gov.it/images/stories/documenti/Strategia_Nazionale_Idrogeno_Linee_guida_preliminari_nov20.pdf
[13] https://www.governo.it/sites/governo.it/files/PNRR.pdf

technology with the national and EU targets toward the decarbonization of the energy system by 2050.

2. Methodology

The main aim of this paper is the evaluation of the stock of heating systems in residential buildings in Italy. The study will assess the future evolution of the number of heating appliances, considering different levels of detail, including the level (autonomous vs centralized), the fuel, and the technology. The residential dwellings and buildings that have been considered are either occupied by residents or not occupied (second houses, vacant houses). We did not consider commercial/public buildings and industrial buildings in this study.

2.1. Input data on historical trends

The estimation model has been based on different input data, including historical trends of market data for heating systems. The existing stock of heating systems has been estimated by an update of the available data published by ISTAT for 2011, by considering the evolution of the heating systems market over the years 2011-2019 (retrieved from heating manufacturers associations' statistics[14] and Bosch internal expertise). To improve the accuracy of the study, the available data have also been compared with other sources to evaluate potential issues or differences, including outputs from CRESME[15] / EUROCONSTRUCT[16], Agenzia delle Entrate[17], BRG Consulting[18], MISE[19]. Moreover, the results have also been compared with different estimations of the heating stock in the residential sector that are available for different years from a range of studies (ENEA[20], CRESME[21], BRG Consulting[22], HARP[23], SNAM-TERNA[24], European Commission[25]).

In the historical data we considered only heating appliances, i.e. we excluded all the appliances that supply only cooling or domestic hot water. In addition, in autonomous heating we included

[14] ANIMA/ Assotermica (Mercato), ANIMA/ Assoclima (Studi di mercato)
[15] XXVI Rapporto congiunturale e previsionale Cresme: Il mercato delle costruzioni 2018-2023
[16] 85th EUROCONSTRUCT Country Report (2018)
[17] Osservatorio Mercato immobiliare: STATISTICHE CATASTALI 2019
[18] The European Heating Product Markets - 2020 Edition
[19] STREPIN - Strategia per la riqualificazione energetica del parco immobiliare nazionale (Documento per consultazione pubblica – 25 Novembre 2020)
[20] Rapporto Annuale Efficienza Energetica (RAEE) 2020
[21] 4° RAPPORTO CONGIUNTURALE E PREVISIONALE: Il mercato dell'installazione degli impianti negli edifici in Italia 2018-2021
[22] The European Heating Product Markets - 2020 Edition
[23] Building vs heating stock (space and water) matrix, EU and country level November 2019
[24] Documento di Descrizione degli Scenari 2019
[25] Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables)

fixed or heating appliances that are the only heating system into the house (such as wood or pellet stoves or air to air heat pumps that are the only heating plant into the house). In centralized heating, we included district heating systems, which are an important technology with a significant share in different cities. However, this information has been integrated from the specific information published by AIRU[26], the Italian association of district heating networks.

2.2. Heating stock estimation

The goal of the study is to perform an annual estimation of the future evolution of the heating systems stock, up to 2050. The evolution of the stock, considering different levels, fuels and technologies, is modelled by considering different assumptions and drivers, based on different scenarios hypotheses that are explained in the following sections.

The model, which has been developed with the R software environment[27], estimates the evolution of the stock based on the age of the units, which are progressively replaced after their technical lifetime. The age of the historical stock has been calculated by considering the available data on heating systems installations and replacements, and the technical life-time of the units has been considered to be on average 20 years (with the exception of air-to-air heat pumps, that have a shorter life-time, of 10 years).

The required input data include the market shares of the different technologies for replacements and renovations and for the installation in new buildings. The model is applied to three different scenarios, that are explained in detail in Section 2.3.

The technologies that are considered in this study are the following:

- biomass boilers and biomass stoves;
- diesel non-condensing boilers and diesel condensing boilers;
- natural gas non-condensing boilers, natural gas condensing boilers and natural gas heat pumps;
- hydrogen-ready boilers and hydrogen boilers (only for a scenario);
- air-to-water heat pumps, water-to-water heat pumps, air-based heat pumps;
- hybrid systems (composed by a natural gas boiler and a heat pump);
- district heating.

[26] AIRU, Annuari del teleriscaldamento urbano, https://www.airu.it/teleriscaldamento/
[27] https://www.r-project.org/

The evolution of the future stock of all these technologies, for both autonomous heating and centralized heating systems, is estimated by accounting for the annual installations in new buildings, the replacements and renovations and the dismissal of systems that reached their technical lifetime. The initial age distribution of the heating systems has been estimated starting from available market data for the years 1998-2019. Moreover, the assumptions have been integrated with a comparison with available information from the heating systems census for Lombardy[28], which reports detailed information for more than 3 million units.

The only exception has been done for biomass stoves, due to the fact that they are representing a different kind of product, which is not generally included into the statistics of heating system manufacturers. There are data available for this product[29], but are not very detailed and they include either the stoves that are the only heating system into the house either the ones that has been used as a support into a single room to another heating system (this are represent the main of the share of biomass stoves and they are out of scope of our analysis). For this reason, the number of biomass stoves has been estimated with a separate logic, but it has been integrated in the results due to the fact that wood biomass represents a non-negligible share of the final energy consumption in the Italian residential sector.

2.3. Future scenarios

This study is based on three different scenarios. The *Baseline scenario* has the goal of providing a reference without any specific target, but only extrapolating the current trend with some corrections based on expert opinions. The *Green Gas scenario* has been defined to evaluate the potential contribution of hydrogen and biomethane in supporting the decarbonization of the residential sector. Conversely, the *Electrification scenario* has the goal of analysing a stronger deployment of electricity-based technologies. These two scenarios have been defined as "boundary" scenarios, while the actual future evolution of the residential sector will likely fall in between these two narratives.

[28] http://www.curit.it/home
[29] AIEL, Libro Bianco sul futuro del riscaldamento a legna e pellet

2.3.1. Common hypotheses across scenarios

The future evolution of the heating market and stock is estimated by considering some common hypotheses across the scenarios, with the idea of limiting the number of parameters that vary in the scenarios to obtain comparable results and highlight the effects of the main drivers.

A main assumption of this study is the fact that we assumed a constant number of replacements and renovations of heating systems in line with the average figures of the last five years. This hypothesis is justified by the fact that we expect potential variations over the years that are difficult to forecast. Looking at historical values, replacement and renovation figures have often shown “up-and-down” trends, mainly due to legislation changes and incentives, but subsequently reabsorbed over a reasonably long period of time, and any potential future assumption may be difficult to justify. For this reason, we kept the simpler approach to estimate the future size of the market.

Considering new buildings, a first assumption is related to the evolution of the number of the new buildings in the Italian residential sector that are considered in our scenarios. Historical data are available for the number of annual new dwellings that are built in Italy, divided into single-family houses and multi-family houses (source CRESME[30] /EUROCONSTRUCT[31]). Based on this data, we have defined a forecast of future new buildings by considering a gradual reduction of new buildings (considering only the consumption of new land), to reach the goal of "No net land take by 2050". We considered a 3% decrease per year of the total number of new buildings on open space or farmland. Still, an increasing number of new buildings will be the result of demolitions and reconstructions of old buildings (since in our model they are considered as a deep renovation). Moreover, we have assumed that there will be no change in the share between Autonomous/Centralized heating systems, due to the lack of reliable historical data to draw an accurate forecast.

The evolution of the technologies in new buildings is quite similar across scenarios, although with slight variations in some specific figures. The estimation has been based on Bosch TT experience, also supported by the available historical data for the technologies installed in new buildings/dwellings, based on national data from BRG Consulting[32] /ISTAT[33]. In line with the national regulations that are in place, we assumed no gas technologies in new buildings supplied by autonomous heating systems starting in 2020, and a strong decrease in centralized heating

[30] XXVI Rapporto congiunturale e previsionale Cresme: Il mercato delle costruzioni 2018-2023
[31] 85th EUROCONSTRUCT Country Report (2018)
[32] The European Heating Product Markets - 2020 Edition
[33] Rilevazione Permessi di Costruire (Annuali)

applications (with installations of gas appliances reaching a share of 67% in 2020, 11% by 2030, 2% by 2040 and 0% by 2050). In parallel, there is a shift towards electrical heat pumps that fill this gap, including air-based systems, that increase their share against "air to water heat pumps" (in 2050 air-based systems reach 53% new installations as autonomous systems and 29% as centralized ones). Air-based systems include currently only “air to air heat pumps” (Split, Multi Split and VRF), but in a close future both heat pump and a HRV in a same box, that bring inside to the dwelling air (heated or cooled), renovation air for air hygiene purpose and domestic hot water.

The effects of existing incentives (including "Ecobonus 110% and "Sconto in fattura/Cessione del credito") on the future installations of heating plants have not been explicitly considered. In general, on the medium- and long-term, these measures generally push an increasing replacement rate in the years in which they are available, but they are followed by a drop in installations, due to the anticipations in replacements (similar effects have been observed in the past). Moreover, we currently have only few months of data (since September 2020) to evaluate the real effects of these mechanisms. So, it is not possible at this stage to properly understand exactly their effects on the market. Moreover, other future incentives may alter the market in different ways as well.

Finally, specific assumptions have been made for district heating plants, both for new and existing buildings. We estimate a slight increase in the district heating share in new buildings, from a 3% level in centralized heating in 2020, to 8% in 2050. In existing buildings, we assume that those that are currently supplied by district heating will not switch towards other technologies, and that connections will constantly increase by 1000 units per year. These assumptions are required, since district heating connections are generally facing different logics compared to other heating generation systems. There may be specific regulations and economic agreements with the suppliers that limit the flexibility of the customers in changing their heating system, as historical figures show.

2.3.2. Baseline scenario

The *Baseline scenario* is a bottom-up scenario that is driven by the future extrapolation of historical trends, integrated with the expert opinion of Bosch. This scenario is not designed to reach any decarbonization goal by 2050, but it is assumed to follow the past trends and the existing legislation. In accordance with this perspective, in the baseline scenario we excluded the

use of hydrogen for residential heating, in the hypothesis that its use will be prioritized in other sectors.

We considered the same technologies available today for the future installations. However, within each technology, we considered the possible future improvements of the appliances. For example, we considered the F-Gas development for heat pumps and the future air-based appliances may also include the bundle of a heat pump and a HRV in a same box.

2.3.3. Green Gas scenario

The Green Gas scenario has been defined with a top-down approach. We considered the achievement of EU objectives for 2050, reaching a potential climate-neutral heating of the residential sector. We considered the integration of a low-carbon hydrogen quota (either blue and/or green, to be defined) within the existing gas network (including blending and dedicated infrastructure), together to biomethane and/or synthetic methane, in parallel with the electrification of heating. The electricity supplied to final users is expected to be totally generated from low-carbon sources by 2050.

Considering the composition of the gas supplied to the natural gas grid, we assume a progressive increase of renewable natural gas (biomethane), that reaches 15% in energy content by 2030, 50% by 2040 and 100% by 2050. An additional constraint of this scenario is that the assumption that the total consumption of biomethane in 2050 stays below 60 TWh, which is 40% of the estimated availability of biomethane in Italy (estimated around 15 billion cubic meters by 2050).

Considering hydrogen, we assume that in addition to dedicated “hydrogen valleys”, the volumetric share of hydrogen blending in the natural gas grid will reach 10% by 2040 and 20% by 2050. By 2030, with the development of selected “Hydrogen valleys”, hydrogen for heating is tested in a limited number of applications, mostly driven by other sectors. Our hypothesis is that by 2030 hydrogen technology reaches around 10,000 H_2 boilers installed in households. By 2040, hydrogen for heating is gaining momentum, thanks to a wider availability and lower costs, and installed hydrogen boilers reach 700,000 units. By 2050, Hydrogen reaches a significant share of final energy uses, with more than 2.6 million H_2 boilers installed in households, in a context with a fully renewable gas distributed in networks.

Specifically, we assume the first commercial installations of hydrogen and hydrogen-ready boilers (boilers that can be easily adapted from methane operation to hydrogen operation) in 2029, after a proper time interval for pilot testing and certification procedures. For hydrogen-ready boilers,

we assume that they are modified to be operated by hydrogen two years after their installation. Finally, we assume that whenever a "hydrogen valley" is planned, at least 2 years before its opening it becomes mandatory in the area to replace any dismissed gas boiler with a H_2-ready one. Before switching the gas network to hydrogen, all the existing non- H_2-ready boilers need to be directly replaced with H_2 boilers.

2.3.4. Electrification scenario

The Electrification scenario has also been defined with a top-down approach, with the same goals of the previous scenario. In this case, we did not consider hydrogen for residential heating, but we did include a share of biomethane/synthetic methane. Like in the previous scenario, the electricity supplied to final users is expected to be totally generated from low-carbon sources by 2050. Also, we again assume a progressive increase of renewable natural gas (biomethane), that reaches 15% in energy content by 2030, 50% by 2040 and 100% by 2050. In this case the final consumption of biomethane remains well below the value of 60 TWh, which is 40% of the estimated availability of biomethane in Italy.

In this scenario, we assume that the main role in the decarbonisation of heating is done by heat pumps, although it is clear that their market growth will be limited by a number of factors (including some limitations in available space in buildings, operating temperatures, etc.). Still, we considered for this scenario a strong improvement of electrical technologies (especially air-to-water heat pumps), including the size reduction of appliances and the high temperature supply of hot water (that allows them to be used to replace heating systems that are equipped with radiators).

2.4. Final energy consumption and CO_2 emissions

In addition to the estimation of the total stock of heating systems, the output of the model has also been used to calculate an approximated estimation of the final energy consumption of residential heating by fuel, to compare these results with the decarbonization targets that have been set by the EU.

The final energy consumption for each energy source has been estimated by computing an average energy consumption per unit, by comparing the historical heating stock and the final energy consumption data available from the National Energy Balance[34]. This comparison has

[34] https://dgsaie.mise.gov.it/bilancio-energetico-nazionale

been done for biomass boilers, diesel boilers and natural gas boilers, and an average consumption value has been considered to account for the weather variations across the years. The data on electricity consumption for heat pumps has been estimated based on a comparison of annual coefficients of performance with boilers efficiency, due to a lack of data on the actual electricity consumption of heat pumps in Italy.

An additional hypothesis has been a total decrease of the energy demand of the building stock of 25% by 2050 (in line with the goal of 0,8% yearly energy efficiency improvement foreseen into NECP for Italy updated in 2020), starting from 2020 data, to take into account the energy efficiency measures that are being adopted in buildings. This assumption is a clear approximation, but a detailed estimation of the energy consumption is beyond the scope of this work, which is focused on the market shares of different technologies and their evolution in the stock of heating systems.

The CO_2 emissions of residential heating have been estimated by considering average emission factors for different fuels, based on literature data[35]. Specific hypotheses for Italy have been considered, including historical figures for electricity intensity[36] and heat supplied from district heating networks, whose emissions have been allocated to the heating sector (depending on the amount of energy consumption of these two energy carriers). Future emission factors have been estimated assuming a fully low-carbon generation for both electricity and heat by 2050. In accordance with international statistics, CO_2 emissions for biomass and biomethane have been considered to be null, due to the fact that these fuels are carbon neutral. Finally, hydrogen emissions have been assumed to be zero, given the fact that hydrogen use in final uses makes sense only if it can be produced from low-carbon sources.

[35] https://www.covenantofmayors.eu/IMG/pdf/technical_annex_en.pdf

[36] http://www.sinanet.isprambiente.it/it/sia-ispra/serie-storiche-emissioni/fattori-di-emissione-per-la-produzione-ed-il-consumo-di-energia-elettrica-in-italia/at_download/file

3. Results

This section presents the main results of this study, including the evolution of the heating systems stock, the share of installations, as well as their estimated energy consumption and carbon dioxide emissions.

3.1. Stock of residential heating systems

The main output of this work is the analysis of the evolution of the stock of heating systems considering different technologies, comparing alternative scenarios based on the assumptions presented in the previous sections.

Figure 1 and Figure 2 present the distribution of the estimated stock by type of fuel, for autonomous and centralized heating systems respectively. The share of natural gas systems, which stands at around 75% of autonomous units and 60% of centralized units in 2020, is decreasing in every scenario, although with different levels of intensity.

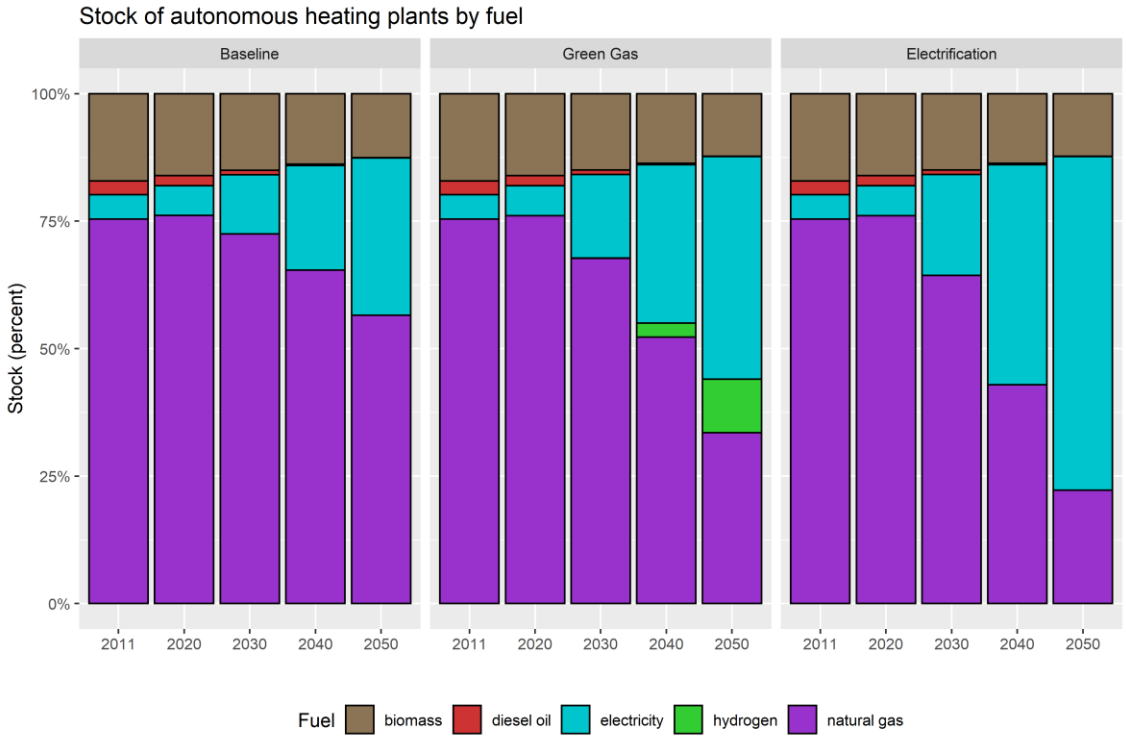

Figure 1 – Share of the stock of autonomous heating plants, by fuel and by scenario.

Autonomous heating systems based on natural gas, which are almost 19 million in 2020, will decrease in 2050 to 14.2 million units in the *Baseline* scenario, 8.4 million in the *Green Gas*

scenario and 5.6 million in the *Electrification* scenario. It is important to remember that in the future the gas that they will burn will contain an increasing share of carbon neutral methane, either from biomethane or synthetic methane (produced from low-carbon hydrogen and captured carbon dioxide). In relative terms, such a decrease will result in a share of gas-based systems (excluding hydrogen) between 22% and 57%, depending on the scenario. Hydrogen autonomous boilers, which are considered only in the *Green Gas* scenario, will reach 2.6 million units by 2050, around 10% of the total stock (compared to 33% of gas-based boilers in the same scenario). This decrease of gas-based unit will be balanced by an increase of electricity-based heating systems, which are expected to increase from 1.4 million units in 2020 to a total stock between 7.7 and 16.4 million units by 2050, depending on the scenario. The share of biomass will slightly decrease in all the scenarios, in line with the fact that while biomass will play an important role in heating decarbonization, it also shows some problems in terms of local pollution, which is a major concern in many Italian regions, especially in the Po Valley. Diesel units, which are already a marginal share in 2020, will gradually decrease and disappear in 2050 in all the scenarios.

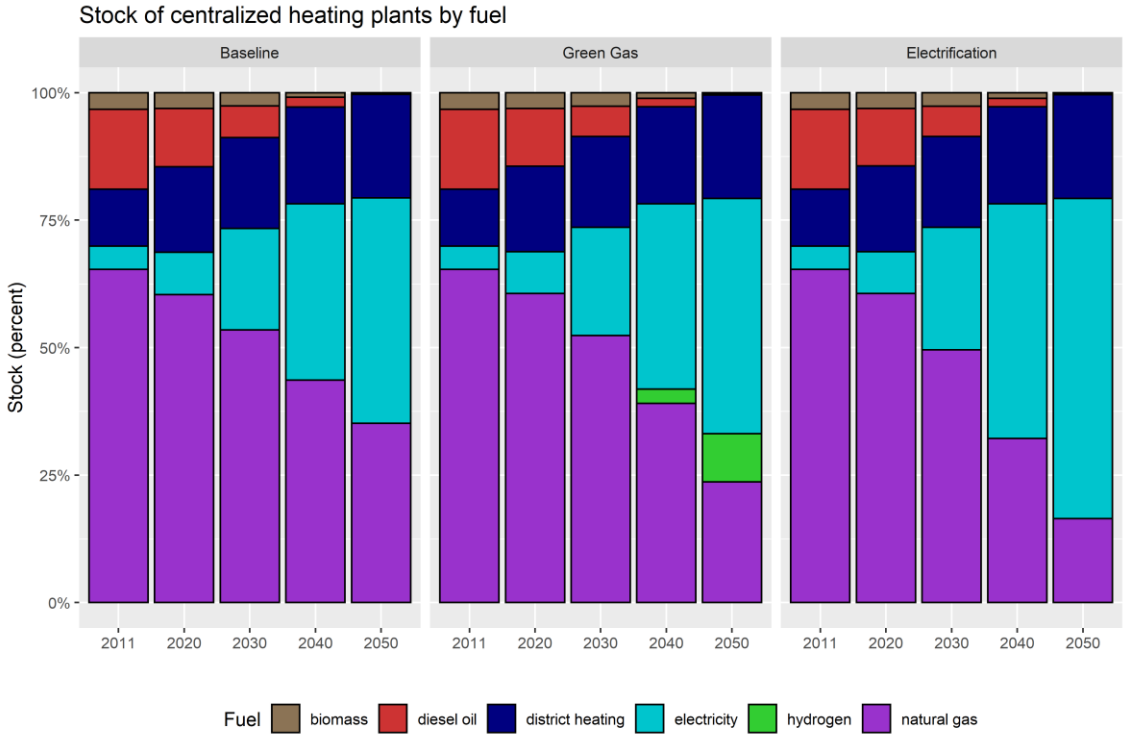

Figure 2 – Share of the stock of centralized heating plants, by fuel and by scenario.

Similar trends can be observed for centralized heating systems. In this segment, natural gas boilers already show a lower share in 2020, due to the presence of district heating technology

(which is not present in autonomous heating) as well as a non-marginal share of diesel boilers (around 11%). In absolute terms, centralized gas-based boilers are expected to decrease from around 300 thousand units in 2020, to 95-200 thousand units by 2050 in the three scenarios, representing a share of 17-36% (excluding hydrogen, which reaches 53 thousand units in the *Green Gas* scenario, around 9% of the total stock). As discussed for autonomous heating, these units will also operate on an increasing share of biomethane or synthetic methane. The share of district heating systems will slightly increase in all the scenarios, from 17% in 2020 to 20% in 2050, given the potential role of this solution to decarbonize specific areas, notably high-density urban environments. A detailed analysis of district heating dynamics is beyond the scope of this study, but we assume that in all the scenarios low-carbon sources will play an increasing role in district heating systems. Also in this case, the decrease of diesel and natural gas units will be compensated by electricity-based systems, that will increase from the 42 thousand units in 2020 to 250-355 thousand units, depending on the scenario.

Additional details can be found in Figure 3 and Figure 4, which represent the evolution of the total stock for each specific technology, considering autonomous and centralized systems.

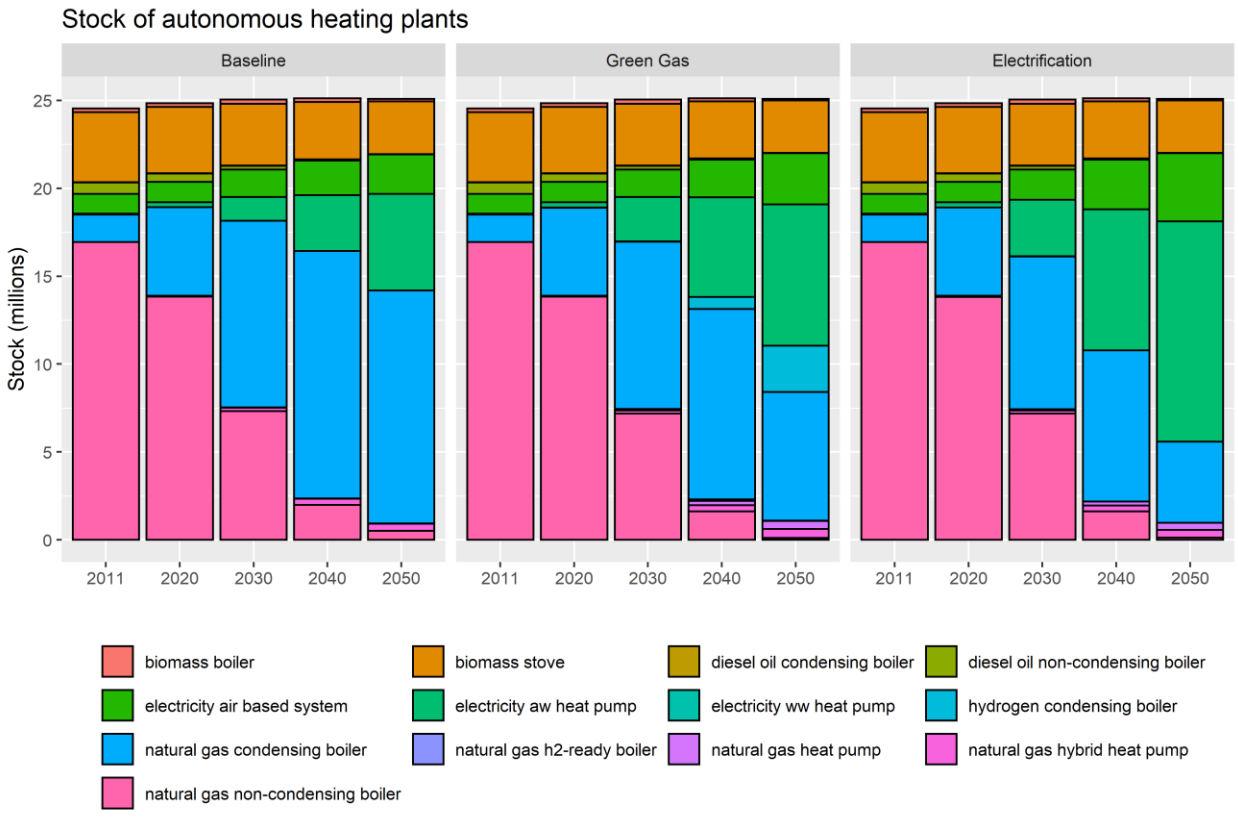

Figure 3 – Total stock of autonomous heating plants, by technology and by scenario.

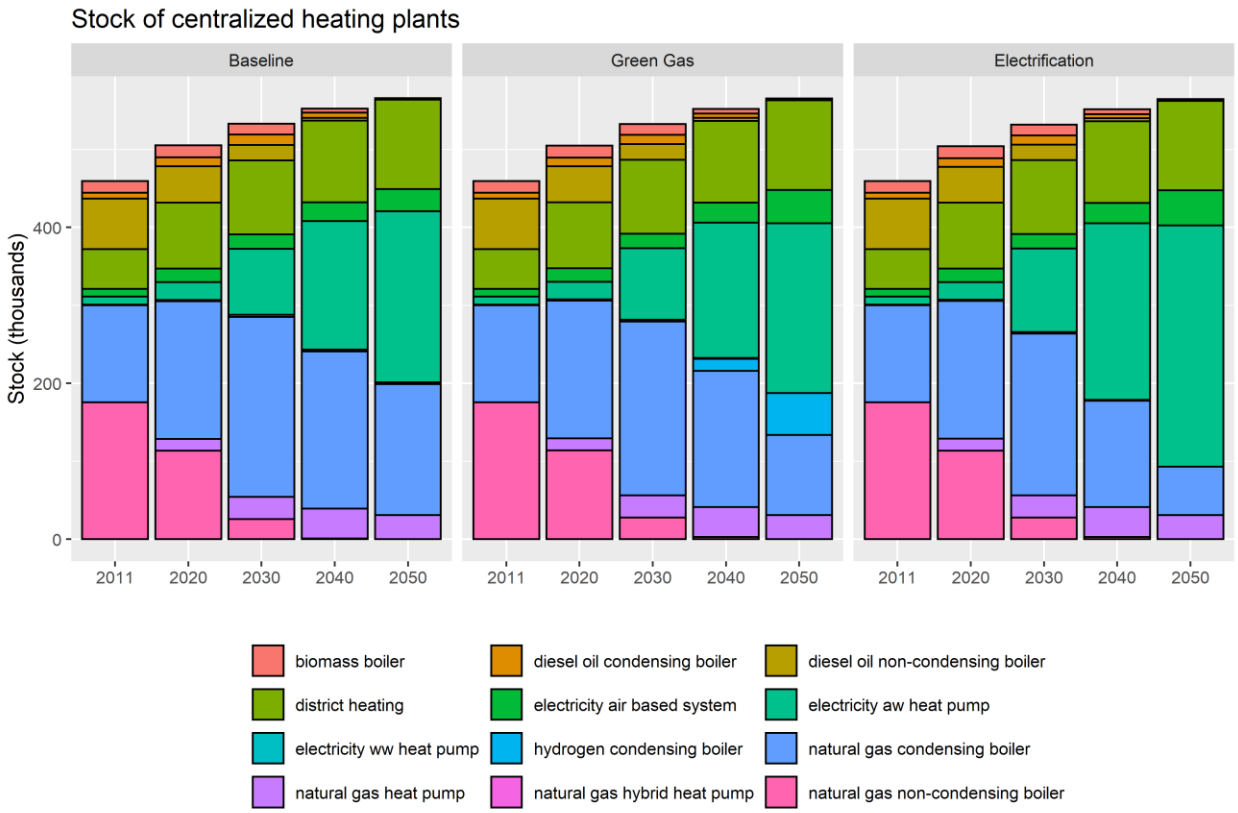

Figure 4 – Total stock of centralized heating plants, by technology and by scenario.

Compared to the previous charts, it is possible to see the strong shift from non-condensing boilers towards condensing boilers, as well as the relative shares of different kinds of heat pumps.

3.2. Installations of residential heating systems

The heating plants' stock presented in the previous section is clearly the result of the evolution of the annual installations of different technologies. Just like what happens in other sectors, such as the evolution of passenger cars, any technological shift in the stock happens in parallel with stronger shifts in the annual sales and installations, due to the inertia of the replacement of the units in operation. For this reason, also a theoretical sudden and total shift towards a new technology in annual installations would require many year to generate a comparable effect on the operating stock.

Figure 5 represents the market share of autonomous heating plants, including the replacements, renovations and installations in new buildings. In all the scenarios the share of natural gas boilers

decreases, and the share of heat pumps increases, but this effect is much stronger in the *Electrification* scenario. As mentioned above, this scenario should represent a "boundary" scenario, which has been defined to evaluate the potential limits of electrifying residential heating in Italy. As the chart clearly shows, the market share of air-to-water heat pumps has a massive increase from 2020 to 2030, which will likely require a range of supporting measures, including targeted incentives and regulations, and in some cases the upgrade of distribution grids. It is also important to note that the role of heat pumps will be significant also in the other two scenarios, although with a lower rate. This challenging aspect, which is a crucial step to decarbonize the heating system, will be further addressed in the Discussion section.

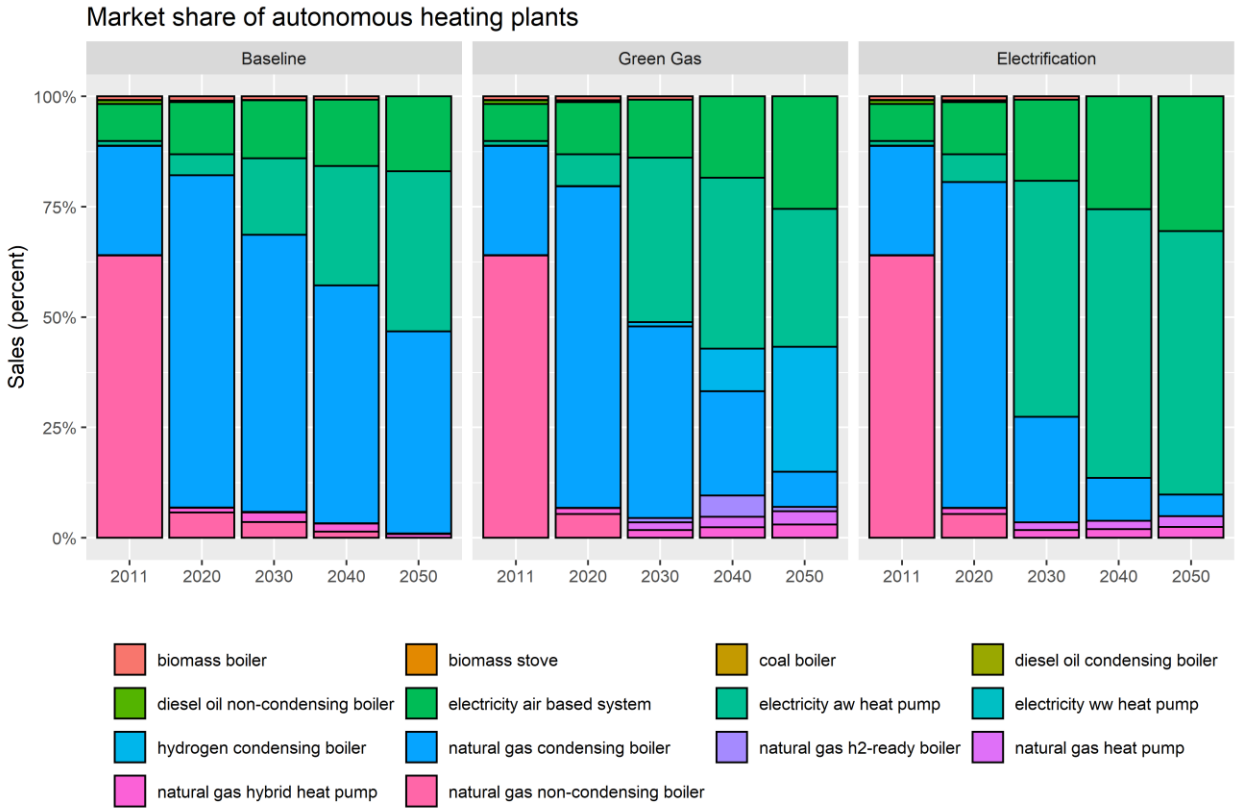

Figure 5 – Market share of autonomous heating plants, by technology and by scenario.

Similar trends are considered for the market share of centralized heating plants, as represented in Figure 6. Also in this case air-to-water heat pumps are expected to show a significant increase of their market share, especially in the *Electrification* scenario. Again, the strongest increase will be required in the next decade, as a strong shift is urgently needed to reach the challenging

targets ahead. In the *Green Gas* scenario, hydrogen boilers will play a role after 2030, since the hydrogen supply chain is not expected to reach the commercial availability in a shorter time frame.

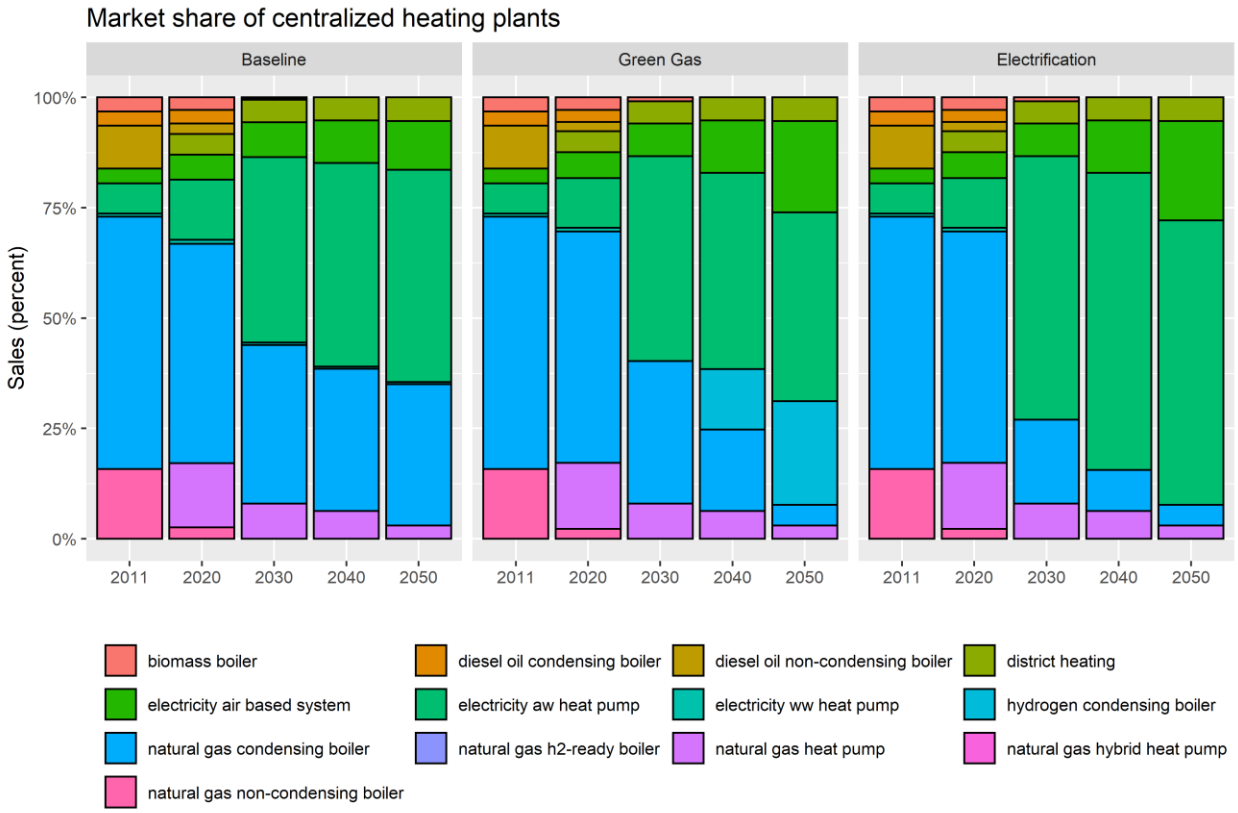

Figure 6 – Market share of centralized heating plants, by technology and by scenario.

3.3. Energy consumption and emissions

Finally, an approximate estimation of the final energy consumption of the residential heating sector has been performed. As already mentioned previously, a detailed estimation of the energy consumption is beyond the scope of this work, but a preliminary assessment is required to verify the compliance of the results with the Italian and EU decarbonization targets.

The following charts represent the final energy consumption for residential buildings' heating, divided by energy source. The results for the Baseline scenario are reported in Figure 7, showing the significant role that will still be played by natural gas on the long term, as already reported in the previous discussion on the trends of the heating stock. Different figures emerge for the Green Gas and the Electrification scenarios, as reported in Figure 8 and Figure 9 respectively. In those

scenarios, on the long term, a rise of electricity and biomethane (and hydrogen in the Green Gas scenario) will allow reaching a decarbonized heating sector. Those figures confirm again that both energy carriers will be needed to reach such a challenging goal. Although each scenario focus on a specific type of technology, it is clear that no technology alone will be sufficient to reach the challenging targets ahead.

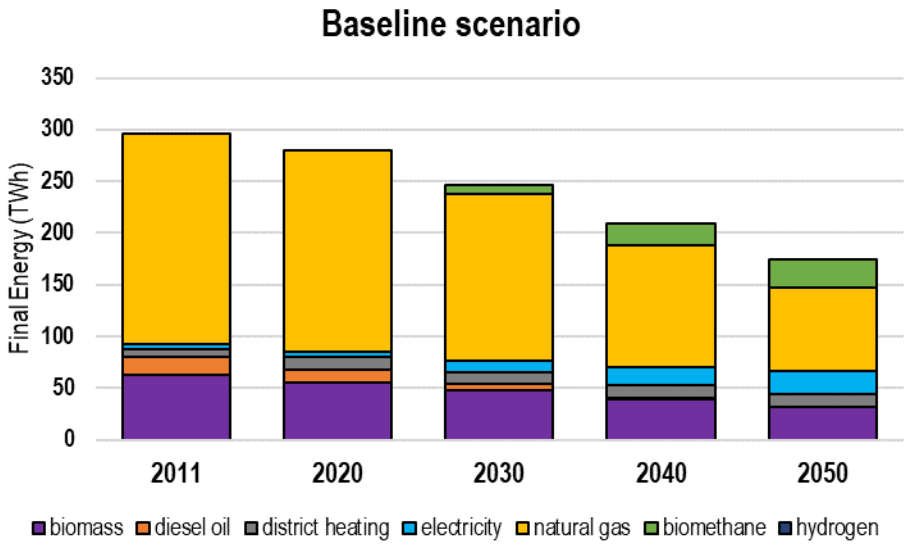

Figure 7 – Final energy consumption for residential buildings' heating, by energy source (Baseline scenario).

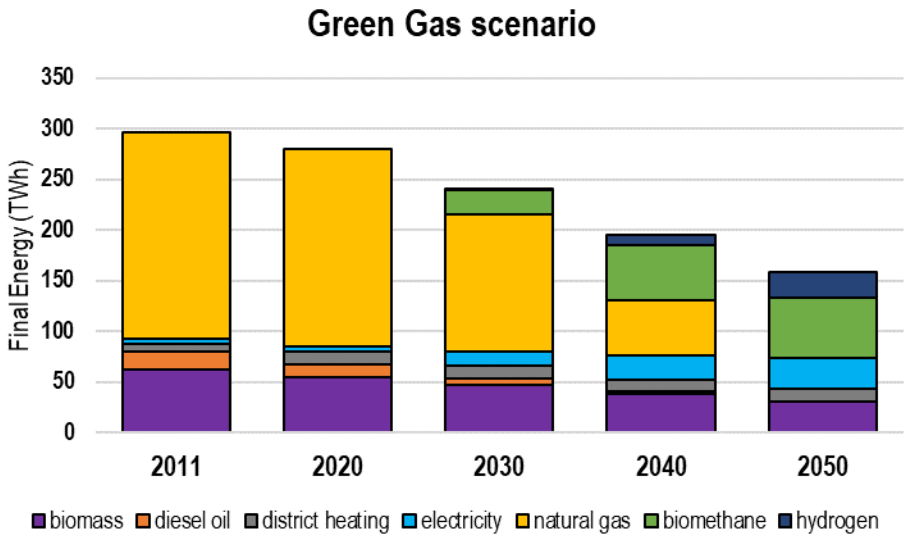

Figure 8 – Final energy consumption for residential buildings' heating, by energy source (Green Gas scenario).

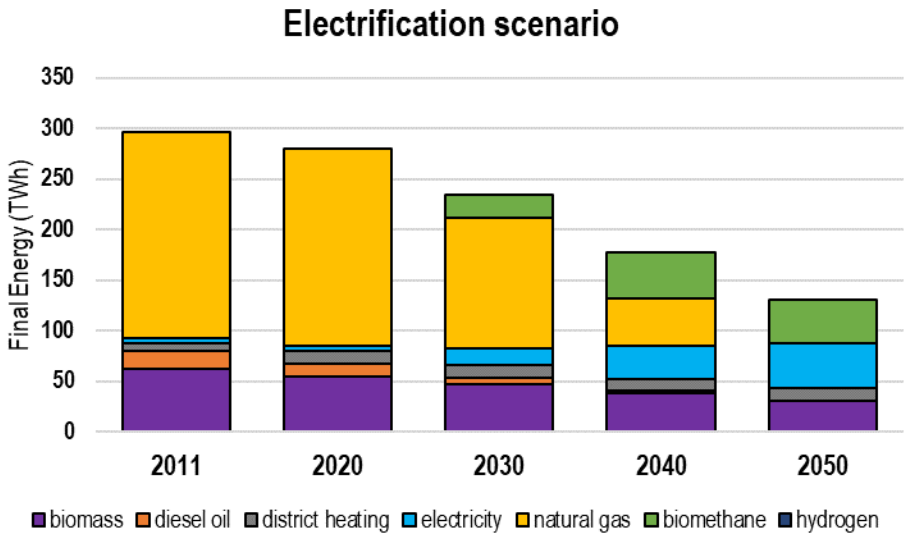

Figure 9 – Final energy consumption for residential buildings' heating, by energy source (Electrification scenario).

Finally, Figure 10 shows the estimated CO_2 emissions related to residential buildings heating, with the Green Gas and Electrification scenarios that reach a total decarbonization in 2050. Conversely, figures related to the baseline scenario highlight that by 2050 emissions will represent around 16 Mt, representing a 64% decrease from 2020 level, but not enough to reach the decarbonization targets. On the other hand, Green Gas and Electrification scenarios show 30% less emissions in 2030 compared to 2020 (with an absolute level of 32-33 Mt), and 70% less by 2040 (with an absolute value of 14 Mt).

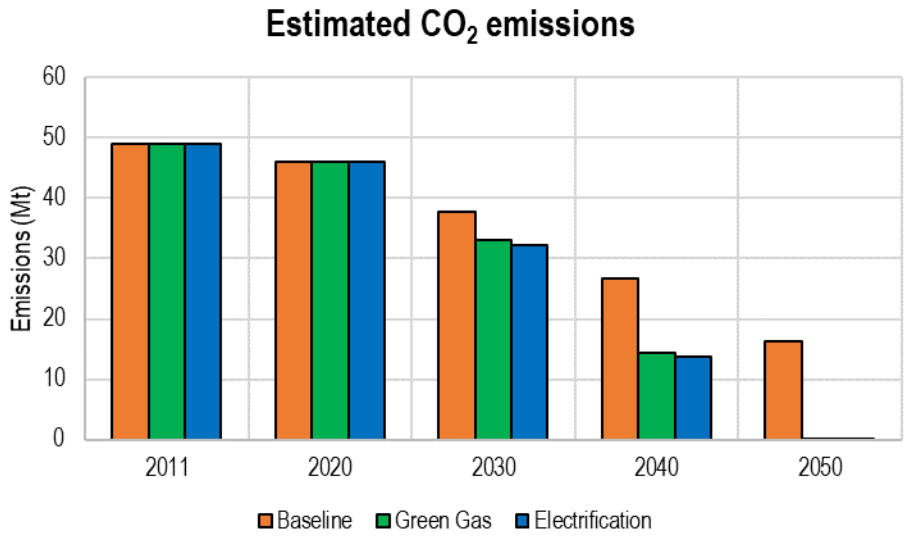

Figure 10 – Estimated CO_2 emissions for residential heating in different scenarios.

4. Discussion

This study shows that with the current trend and technology market shares into replacements and renovations, represented by the *Baseline* scenario, the heating stock would progressively change into the next years, with an increase of electrical appliances and a progressive reduction in gas-based ones (in which we would see a shift from conventional to condensing boilers). However, in the *Baseline* scenario, also in 2050 natural gas would remain the main source for heating, representing more than 50% of final energy consumption due to about 14 million autonomous and 0,2 million centralized units, followed by electricity, representing 13% of the final energy consumption, 7 million autonomous units and 0,25 million centralized units. Considering the gas network, there would be a share of bio-methane from 2030 (5%), increasing progressively to reach a 25% level in 2050. There will also be a complete switch from conventional to condensing, and more efficient, boilers. The residential sector would improve both in terms of energy consumption and CO_2 emissions, but it would fall short from the EU goal to have a decarbonized building sector.

This means that significant changes are required in the building sector to reach the EU target. This goal, as showed in the *Electrification* scenario, could be reached by pushing towards a stronger shift from fossil fuels to electrical technologies: they are more efficient, and when combined with green electricity production they represent a low-carbon heating solution. Currently, the replacement of a fossil fuel (natural gas or diesel oil) boiler with an electrical heat pump requires, in most cases, a significant renovation of the heating system, including the heating distribution and terminals. Furthermore, considering autonomous heating, the footprint of current heat pumps is higher than compared to boilers, and they also need an outdoor space for the installation. This could be a strong limitation to the retrofit with an electrical appliance, especially in the apartments in condominiums with autonomous heating in dense urban areas, where every apartment has only its own essential living space.

Our estimation is that there are currently about 10 million of dwellings in condominiums with autonomous heating plants, of which less than 1% are heated by electricity and for which there could be the two critical aspects showed above for a shift toward electricity heating solutions. Heat pumps manufacturer are working to improve these appliances, to reduce the footprint necessary for their installation (by developing more compact products), as well as to increase the output temperature of the water, thanks to new refrigerants, in order to allow the replacement of the current boilers without any change of the distribution systems and terminals.

The rate of big renovations required in the *Electrification* scenario could be estimated to be higher than 2% per year after 2030 (STREPIN[37] shows 1,2% per year between 2030 and 2050). Thus, to reach the EU decarbonisation goals for residential building, pushing on electrification, Italy would have to speed up the *"big renovation rate"* much more than the rate that has been currently foreseen into the last strategy (STREPIN), resulting in increasing investments and effort. Moreover, in the *Electrification* scenario we assume that the generation, transmission and distribution capacity will increase to accommodate the additional electricity demand, reaching a complete low-carbon electricity generation by 2050. Considering the final users, that would also mean to increase the average available power, from 3 kW/dwelling to at least to 4,5/6 kW/dwelling.

In alternative, the EU goal of decarbonized buildings' heating, as showed into the *Green Gas* scenario, could be also reached with the integration of a low-carbon hydrogen quota (either blue and / or green) within the existing gas network (including both blending with natural gas and dedicated hydrogen infrastructure), together to biomethane and/or synthetic methane, in parallel with the electrification of heating. According all the last available information, green gases (bio-methane and green hydrogen) would start to be available into the distribution network in 2030 (after proper pilot tests and all the required regulations are developed). After 2030, the availability of green gases would increase progressively, with the aim of supplying heating by 2050 to a maximum of about 11 million autonomous systems (2,6 million hydrogen boilers and 8,4 million boilers working with a mix of 80% bio-methane and 20% hydrogen – in volume) and 190.000 centralized gas boilers. This estimation is based on our last updated information concerning the availability of green gases for residential uses. The discussion on the hydrogen development strategy has been started in Italy in the last months (since the first draft of the Hydrogen Strategy by MiSE in November 2020) and it is not yet clear which will be the expected supply of hydrogen and its planned allocation to final uses (refining, manufacturing sector, transport, buildings, etc.). Our forecast is an optimistic view of the potential development, according to the current information available and the discussion with the main stakeholders, of the potential role of green gases and hydrogen in buildings' heating. Boilers manufacturer are currently working either on developing hydrogen 100% boilers either in boilers that can work with a blend of hydrogen and natural gas. The first prototypes of hydrogen boilers are already used into pilot projects in different European countries. Concerning blending, some of the main manufacturers have certified that all

[37] STREPIN - Strategia per la riqualificazione energetica del parco immobiliare nazionale (Documento per consultazione pubblica – 25 Novembre 2020)

the boilers after 1995 could work correctly with a hydrogen blend up to 10%, and they are working to put into the market boilers that could be able to work with up to 20% of hydrogen.

In comparison with the *Electrification* scenario, the big renovation rate assumed in the *Green Gas* scenario is between 1,1% and 1,2%, after 2030, which is in line with the current assumptions of STREPIN. Thus, a parallel development of electrification and green gases for buildings heating would not require additional investments in heating systems adaptation, with respect to those foreseen in STREPIN.

In the *Green Gas* scenario, it is assumed that hydrogen could be supplied to buildings through the existing infrastructure by 2030. However, as already explained, to reach this goal additional tests are needed, in particular on the compliance of the existing infrastructure and the need of upgrading or changing some specific components (including meters, distribution networks and energy generators such as gas turbines, engines, cooking equipment and boilers). Finally, last but not least, existing regulations and certification procedures need to be updated.

Furthermore, it is of course necessary that green or blue hydrogen will be commercially available by 2030, and with increasing shares in the following years also to be supplied to the residential sector. This assumption will depend on many factors, including the development of the entire hydrogen supply chain in the following years, as well as the evolution and the competition by alternative technologies. The current hydrogen supply chain needs to be improved, by reaching higher levels of conversion efficiency, as well as lower costs for its generation, transportation and storage.

Finally, we want to remark again that in this study the *Electrification* and *Green Gas* scenarios have been defined as “boundary” scenarios, while we expect that the actual future evolution of the residential sector will likely fall in between these two narratives. We believe that to reach the challenging target of decarbonizing our energy system, several technologies will need to be deployed together, and give their contribution based on the competitive advantage that they show for any specific application.

5. Conclusions

This study presents a comparison of alternative scenarios to decarbonize residential buildings' heating in Italy. In our Baseline scenario, based on current trends and policies, energy consumption and emissions will decrease, but fall short of reaching the net-zero target set by the European Union for 2050. We thus explore two additional scenarios, which are mostly relying on either electrification or green gases, which include clean hydrogen and bio-methane.

Our results show that in order to reach a decarbonized residential sector by 2050, strong actions will be needed. In both scenarios, we see that a single solution will not be enough to fulfil the target, and a combination of technologies will be required, together with significant energy efficiency measures, both on buildings insulation and heating systems. In any case, such a result will also need additional measures that are not directly related to buildings themselves, including a 100% generation of electricity from low-carbon sources, a shift from fossil natural gas to renewable gases (including biomethane and potentially clean hydrogen) and district heating networks relying on renewable sources.

Considering hydrogen, our results show that it might play a role in the decarbonization of buildings' heating, representing up to 10% of the total stock of heating systems in 2050. Hydrogen could represent a competitive technology in specific conditions, where the available space may not be enough to install electricity-based solutions, and in the hypothesis that hydrogen is already available for other applications in the area. Moreover, to reach a full decarbonisation of buildings' heating, in 2050 all the gas appliances that are not supplied with pure hydrogen will burn a blend of biomethane and up to 20% of hydrogen. According to our results, they will represent around 30% of the total stock in 2050 in the *Green Gas* scenario.

In fact, we believe that the successful use of hydrogen in buildings will require a significant improvement of its entire supply chain, to decrease its cost and improve energy efficiency in its generation, transportation and storage. Other final sectors look more promising for hydrogen applications in the short term, but if hydrogen becomes a commercially available commodity, its characteristics may represent a significant advantage for some residential heating applications.

In all our scenarios we remark that residential heating will require a strong technological shift, already in the short-term, in parallel with major energy efficiency actions. Also, a comprehensive strategy that includes different sectors will be needed to reach such a challenging decarbonization target within three decades. Both targeted policies and investments will be required, and multiple technologies can contribute by providing specific advantages for different applications.

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