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Decarbonization of the heating sector from a system point of view: the case study of the Lombardy Region.

Pozzi Marianna*, Giuseppe Muliere, Francesco Mezzera, Fabrizio Fattori, Alice Dénarié, Mario Motta, Livio Mazzarella

Department of Energy, Politecnico di Milano, via Lambruschini 4 20156 Milano, Italy

*Corresponding author: marianna.pozzi@polimi.it

Abstract. This work aims at defining the optimal technological mix which minimizes the total cost of the energy system in 2030 in the Lombardy region, in northern Italy. The goal is reached through a bottom-up model built on a linear optimization problem considering different technical and economic inputs and constraints. Civil sector is one of the sectors to focus on for the decarbonization process. Different areas, types of buildings and thermal systems are included in the model to consider the peculiarities of the available solutions in each context. The overall technological mix is constraint by a CO_2 emission limit. For the civil sector the more the emission is constrained, the higher is the penetrations of electric heat pumps, coupled with envelope retrofit, (10% of the total thermal energy demand) and of district heating (18%), while natural gas boilers decrease (66%). Biomass boilers reach a maximum penetration of 29% in mountain areas. District heating is relevant in areas with available sources (max 29%). Natural gas boilers coupled with air conditioners have an important role and they reach a maximum penetration of 89% in certain areas. Electric heat pumps are quite homogeneous through the areas for residential buildings.

1. Introduction

The decarbonization of the energy system is one of the most debated topics in many States of the world. After the Kyoto Protocol, the Paris Agreement has been signed with the aim of avoid the climate change limiting the increase of the average global temperature to 1.5°C [1]. The main covered points are about the renewable energy sources, the greenhouse gas emission reduction, and the final energy consumption reduction. After this agreement, the European Union Member States set different targets to achieve within before 2020 and then within 2030 and 2050. In Italy, the European Union targets for 2030 and 2050 are translated respectively in two energy plans: the Integrated National Energy and Climate Plan (PNIEC [2]), now under review by the Fit-for-55 package [3] and REPowerEU plan [4], and the Long-Term Strategies (LTS [5]).

In Italy, the civil sector represented about 36% of the greenhouse gas emission and about 40% of the energy consumption in 2019 [6]. Due to its high contribution in term of greenhouse gas emission but also in term of energy demand, the civil sector is expected to have a fundamental role in the Italian decarbonization process. The decarbonization of this sector, together with other sectors, allows to achieve the set targets and to have greater energy independence. Replacing the current used heating technologies with low carbon heating systems and redeveloping the buildings are the main actions to achieve the set targets.

In this sense, several models are developed to analyze the decarbonization of the heating sector in different countries as shown in the literature review of Plazas-Niño et al. [7]. In this paper we use an open-source modelling framework applied to the whole energy system of a specific region in northern Italy, with a higher detail on the heating systems. The resulting model is used to study the best technological mix in 2030 in the region under different decarbonization scenarios. The modelling framework, *OEMOF* (Open Energy MOdelling Framework), is based on a bottom-up linear optimisation problem enabling detailed models in space and time. A similar approach is applied in [8] and [9] through the Resources-Technology Network (RTN) model, a spatio-temporal linear programming model that allows to develop long-term energy system strategies. The strength of the used methodology is the possibility to provide detailed results on each considered sector and technology and compare different possible solutions from the system point of view. Based on this, the aim of this paper is to show the results of the application of such methodology to the decarbonisation of the Lombardy region, with a particular focus on the heating sector.

1.1. Structure of the paper

The paper is structure as follows. The methodology applied to evaluate the optimal technological mix is described in paragraph 2. Paragraph 3. describes the main and most interesting results of its application to the Lombardy region. Finally, paragraph 4. reports the main conclusions.

2. Methodology

This section describes the modelling framework (section 2.1.) and then its application to the energy systems of the case study, with the input data and assumptions used to define the optimal technological mix (section 2.2.).

2.1. OEMOF

OEMOF (Open Energy MOdelling Framework) is an open-source modelling framework based on a linear programming problem and on the graph theory (a detailed description can be found in [10] and [11]). This work makes use of such framework to model the regional energy system in order to define the optimal technological mix best suited to achieve the goal of a given decarbonization scenario. The general optimization problem is made up of:

- *The objective function*, representing the total cost of the system to be minimized (it is the sum of the capital expenditure, CAPEX, and the operational expenditure, OPEX).
- *The decision variables*, representing the energy flows and/or the capacity of technologies and processes (specific investment, variable and fixed costs are associated to these variables).
- *a series of constraints* which guarantee that: (i) the sum of import and local production equals the sum of export and local consumption (plus storage variation) for each commodity in each time step, (ii) the limit of the sources (e.g. market availability and technologies producibility) are respected as well as political goals (e.g. emission limits).

In order to model an energy system and translate it into the optimization problem, OEMOF uses five main elements:

- *Transformers*: technologies or processes, with their related efficiencies and costs, which operate a transformation of a commodity with certain properties into another commodity with different properties (e.g. boilers convert natural gas to heat demand).
- *Energy carriers* (in OEMOF represented by so-called "buses”): “a substance (fuel) or sometimes a phenomenon (energy system) that contains energy that can be later converted to other forms such as mechanical work or heat or to operate chemical or physical processes*”* [12]. In the model, they represent the input or the output of a transformer (e.g. electricity or heat).
- *Sources*: “system from which a commodity can only be obtained or extracted”.

- *Sinks*: “system to which a commodity can be only provided or discharged” (e.g. heating demand).
- *Energy carrier flows* (in OEMOF represented by so-called “flow”): interactions between energy carriers transformers, sources, or sinks.

Figure 1 shows a schematic representation of the relation between the five elements of the OEMOF framework.

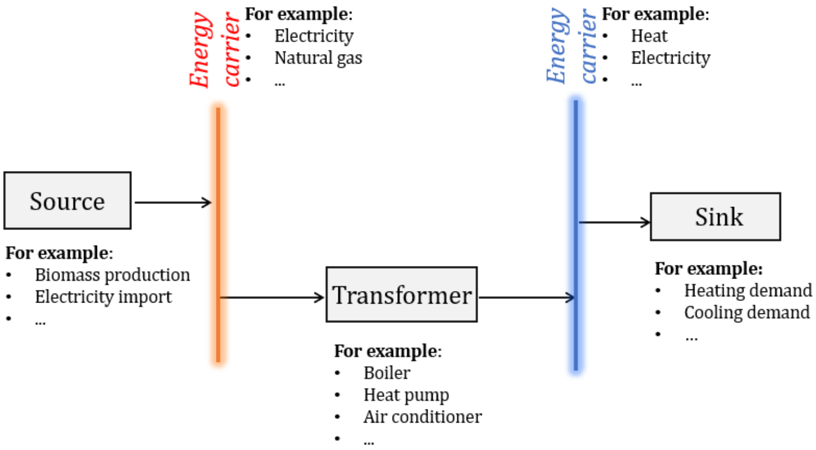

Figure 1. Representation of the relation between the five elements of the OEMOF framework.

Each element of the model can be replicated and combined with different configurations to best represent the energy system. The level of detail can be based on the data availability and the goal of the application. Two main types of technology aggregation can be considered: by technological affinity (e.g. heat pumps of different types can be considered as a single representative heat pump) or by geographical affinity (e.g. specific types of heat pumps within a given area are considered through a single representative technology of that specific type in that specific area). The possible aggregations allow to define the characteristics and the connections of each sector of the energy systems and each territory. It must be highlighted that the optimal technological mix resulting from the optimisation of the problem is defined by the energy system perspective rather than the perspective of final users.

2.2. Characterization of the case study

The model previously described is here applied to the Lombardy region. The latter is the most populous region in Italy with about 10 million inhabitants, with the highest per capita income, and so the highest gross domestic product (GDP). Since the territory is heterogeneous, its different territorial peculiarities, like sources availability and climate, are considered by dividing the region in multiple homogeneous areas. In particular, it is divided into the 17 areas reported in Figure 2. Each area is featured with (i) a specific energy demand, (ii) a specific existing technological mix and (iii) specific availability of sources.

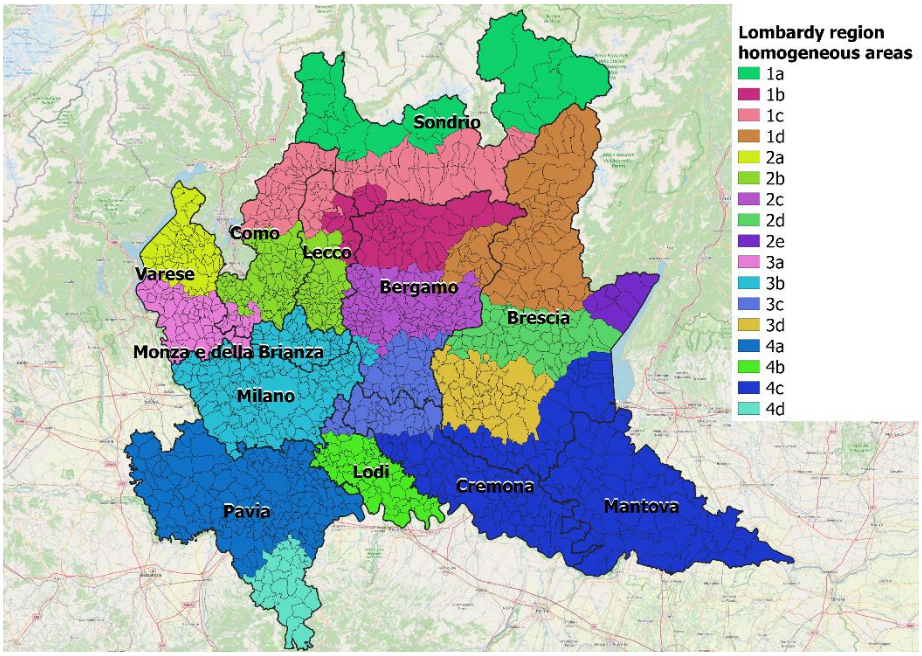

Figure 2. Lombardy region division in 17 homogeneous areas.

2.2.1. Input and assumptions.

The model is applied to the entire energy system, but this paper specifically focuses on the civil sector. This sector is characterized by several possible technical solutions, buildings and thermal systems, with different technical characteristics and availability, depending on the geographical position. Due to these differences, the civil sector must be very detailed within the model. Figure 3 reports a scheme of the reference energy system of the sector (the scheme is applied to each geographical area and is integrated with other sectors, namely industry and transport).

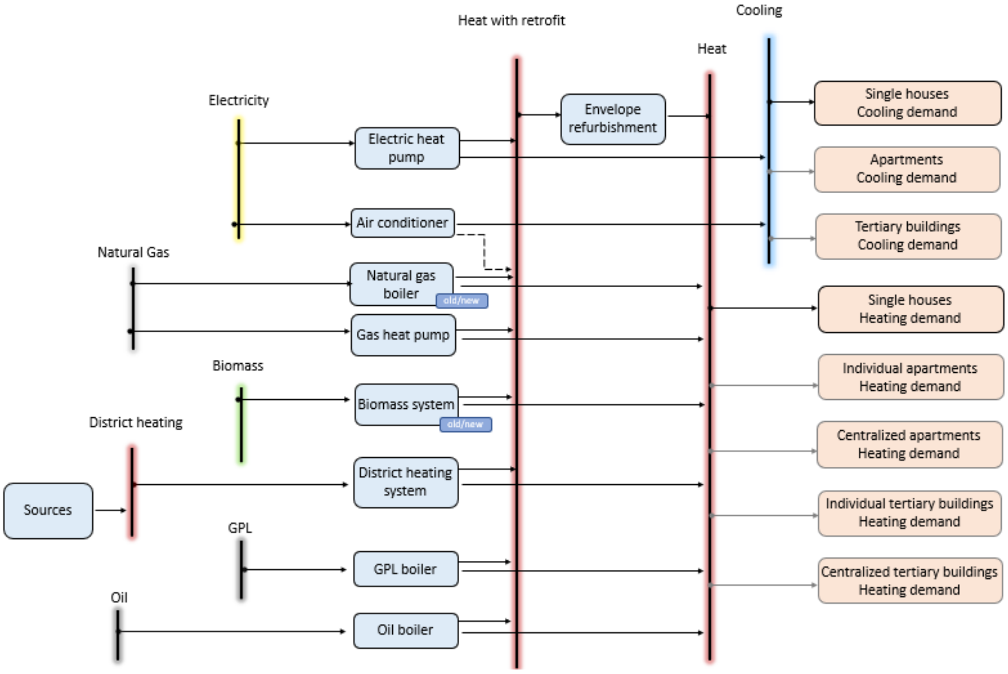

Figure 3. Focus on the civil sector scheme of the energy system inside the model. This scheme is replicated for each considered area.

Technologies and processes are characterized by (i) investment cost, (ii) fixed and variable cost, (iii) efficiency or specific consumption, (iv) remaining installed capacity in the target year (2030) and (v) penetration or availability constrains.

The temporal resolution of the overall model is annual and the spatial resolution is defined by the 17 homogeneous areas. Nevertheless, input data are based on estimations with finer resolution in time and space, depending on the sector and the type of information. For the heating sector, the demands are evaluated based on an annual bottom-up model and the spatial resolution is as fine as the census cells, while efficiency of heat pumps is based on hourly values. In particular, the annual energy demand for space heating is estimated in each census cell starting from open data as the Energy Performance Certification (EPC) Database [13] (CENED), the Italian Buildings and Population Census [14] and the Italian Industry and Services Census [15] (ISTAT) [16]. Values of the annual space heating demand are estimated equalizing it to the heat losses through the envelope, using data about the thermal transmittance and the dispersing surface available from the EPC database. For the residential sector the annual values are obtained for types of building (e.g. single-houses and apartment blocks) and construction ages. The total residential space heating demand is geographically distributed in each census cell based on the number of houses for each type of buildings and construction ages available from the Italian Buildings and Population Census [14]. For the tertiary sector the values of the annual space heating demand specific per floor area are obtained for different subsectors (e.g. offices, schools etc.). The total annual tertiary space heating demand is geographically distributed in each census cell based on the number of employees (available from the Italian Industry and Service Census [15]) and the specific buildings surface per employee in each subsector (estimated from the data in the GSE report [17] and the Agenzia delle Entrate database [18]). The total annual domestic hot water (DHW) demand is estimated in each census cell by multiplying the number of inhabitants available from the Italian Buildings and Population Census [14] by a value of DHW demand per capita estimated from the GSE report [17].

Through the Thermal Systems Cadastre [19] (CURIT) the estimated annual space heating and DHW demand is divided into the different energy carriers considering the percentage calculated as ratio between the installed capacity of an energy carrier and the total installed capacity. The result of the estimation is an energy demand divided into energy carriers (i.e. oil, GPL, natural gas boilers, electricity, district heating and biomass) referring to: (i) single-family houses, (ii) apartments with individual heating systems, (iii) apartments with centralized heating systems, (iv) tertiary buildings with individual heating systems and (v) tertiary buildings with centralized heating systems.

With respect to Figure 3, the technological mix considers different possible solutions:

- *Buildings envelope refurbishment* allows to reduce the energy demand. Buildings retrofit is always coupled with one of the following technologies. The maximum annual retrofit rate is set to 2%, similar to the target rate set by the Italian Long-Term Strategies for the period between 2030 and 2050 [5]. The heating demand after retrofit is calculated assuming the minimum required transmittance set by the “Requisiti Minimi” Decree [20]. Comparing the heating demand before and after retrofit an energy saving of about 70% is obtained. Retrofit is considered in the model as a fictitious efficiency that reduce the heating demand required to the heating systems.
- *Natural gas boilers* are present in the model both as a residual capacity of the current systems and as a new technology with higher efficiency (the efficiency of existing boilers is 80% and the efficiency of new boilers is 90%). It is assumed an annual substitution of these systems equal to at least 4% in residential buildings and to 6% in tertiary buildings.
- *Oil and GPL boilers* are considered as residual capacity (efficiency equal to 70%) without any new installation.
- *Biomass systems* are present in the model both as a residual capacity of the current systems and as a new technology with higher efficiency (replaced systems change their efficiency

from 60% to 80%). A substitution of about 50% of the current systems is exogenously assumed in 2030.

- *Electric heat pumps* can be selected by the model only if coupled with refurbished envelopes and, for residential buildings, with radiant panels. Heat pumps can also satisfy the cooling demand, in competition with air conditioners. Efficiencies differ based on the local climate (SCOP - Seasonal Coefficient Of Performance - ranges from 3 to 3.7, according to the climatic conditions). In rigid climate (heating degree days higher than 3500) electric heat pumps aren't suitable. The technology represents different sub-types of electric heat pumps and the contribution of geothermal heat pumps, in particular, is considered minor due to its high investment cost. The share of sub-types is exogenously set and is reflected in the resulting average cost and efficiency[1].
- *Gas-driven heat pumps* are considered available only for single houses and centralized heating systems without the need to refurbish the envelope (SGUE - Seasonal Gas Utilization Efficiency - ranges from 1.36 to 1.49, according to the climatic conditions). It is assumed a maximum penetration of 10% of the total heating demand.
- *Air conditioners* can work as heat pumps to satisfy the space heat demand during the winter period, though limited on average to 14% of the total heating demand. This average value is calculated for each area considering the overall hours the external temperature is between 10°C and 15°C in each area. The SCOP is considered equal to 2.5.
- *District heating* is supplied by CHP plants, electric heat pumps and industrial heat recovery. It is limited to the technical and economic potential estimated in an external analysis, in which available heat sources and heat demands are matched in space according to their magnitude and their associated costs, as reported in [21].

Solar thermal is considered in the work, but its investment is exogenously driven due to the competition with photovoltaic for rooftop surfaces. In particular, the work uses the additional thermal capacity resulting from the commitment of local policies for the target year 2030 (100 MW additional).

It finally must be highlighted that networks are not explicitly modelled but some external considerations are made. In particular, (i) for the gas network, expansion is not allowed (investments in gas-driven technologies are not allowed where the gas network is not available); (ii) for district heating, the cost of possible network extension (both for transport and distribution) is implicitly considered within the total cost of the system (the cost is specific for each area and it comes with fine geographical resolution from the already cited external work [21]); (iii) for the electricity, the model assumes that a network upgrade is anyway expected and planned due to the increase of the cooling loads and the penetration of electric vehicles.

Table 1 reports the main technical and economic inputs assumed for the considered technological solutions. It is important to underline that the values of the SCOP and SGUE and the energy savings for envelope refurbishment vary by the areas due to the different climatic conditions. The SCOP is calculated according to the equation of Staffell et al. [22] that relates the external temperature and the flow temperature. The SGUE is calculated through a relation between the external temperature and the flow temperature defined through external analyses.

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[1] The reason for setting a unique representative electric heat pump with an exogenous share is that, given the linearity of the model, and without the possibility to differentiate any specific boundary condition, the solver would otherwise choose one best technology among the available ones.

Table 1. Main technical and economic inputs and the main assumptions of the considered solutions.

Technology	**CAPEX**	**OPEX**	**Efficiency**
Envelope refurbishment			About 70% of energy saving
Opaque envelope	105 [€/m2]	0 [€/m2/year]	
Windows	410 [€/m2]	10 [€/m2/year]	
Electric heat pump (a-w) [8-25 kW]	500 [€/kW]	5 [€/kW/year]	SCOP: 3-3.7
Electric heat pump (a-w) [28-50kW]	450 [€/kW]	4.5 [€/kW/year]	SCOP: 3-3.7
Natural gas heat pump	1000 [€/kW]	20 [€/kW/year]	SGUE: 1.36-1.49
Condensing boiler	150 [€/kW]	20 [€/kW/year]	0.9
Biomass system	280 [€/kW]	12.1 [€/kW/year]	0.8

The model also considers the possibility to install *photovoltaic panels* (PV) alone or coupled with an electrical storage. The Lombardy Region maximum potential of photovoltaic capacity is estimated 1.8 GW in single-houses, 3.4 GW in apartment blocks and 1.2 GW in tertiary buildings. These potentials are calculated considering 14% of the total footprint area of single-houses and 12% of the footprint area of apartment blocks and tertiary buildings and an average producibility equal to 150 W/m^2. These percentages take into account the orientation of the roof and the possibility to install PV panels. Buildings' footprint is calculated starting from buildings' surface and number of floors provided by ISTAT [14]. Table 2 summarizes the economic input data of photovoltaic for the civil sector.

Table 2. Economic input data of the PV panels for the civil sector.

Technology	**CAPEX [€/kW]**	**OPEX (fixed) [€/kW/year]**
PV [single houses]	1600	50
PV + storage [single houses]	2600	80
PV [apartment blocks]	1500	45
PV + storage [apartment blocks]	2500	75

The model so far described is run in combination with the other sectors of the energy system considering two different scenarios: (i) without emission constraint and (ii) with an emission constraint compliant with the Fit-for-55 goal [3]. The constraint is applied to all the sectors of the energy system (i.e., industry, transport, agriculture, and civil sectors). Table 3 report the prices and the CO_2 emission factors of the considered fuels.

Table 3. Price and CO_2 emission factor of the considered fuels.

Fuels	**Price [€/MWh]**	**CO_2 Emission factor [kg di CO_2 / MWh]**
Natural Gas	60-137[a]	201.8
Oil	145	264.9
GPL	128	224.6
Electricity	160-460[a]	190.0[b]
Biomass	80	25.0[c]

[a] the range of prices refers to trimestral values registered by ARERA in 2013 [23];
[b] the value is derived from the emission factor estimated by Gargiulo et al. [24] for 2030 in a NECP scenario for the national generation mix and adjusted to consider the more severe Fit for 55 goals;
[c] the value refers only to the imported biomass.

To summarize, the model combines the annual heating demand, the assumptions and the costs previously described to evaluate the optimal technological mix that minimize the total cost for the system while achieving the emission reduction. Each technology can be substituted with the same type of technology but with a higher efficiency or replaced with low carbon heating systems according to the maximum and minimum imposed limits for each technology.

3. Results

This section reports the main results of the application of the model to the Lombardy region with a focus on the civil sector. In particular, the results compare the mix obtained under two different scenarios (with and without a CO_2 emission limit), in each type of buildings and in each area.

Figure 4 shows the overall CO_2 emissions of the system in 2005 (the reference year for the emission reduction target), in 2019 (the latest year before the pandemic) and in 2030 under the two modelled scenarios: (i) without considering any constraint in term of CO_2 emissions reduction (3rd column) and (ii) considering a CO_2 emissions constraint according to the Fit-for-55 package (4th column). The emission reduction scenario according to the Fit-for-55 package aims to reduce the CO_2 emission of the non-ETS sectors of about 44%. Under the constrained scenario an emission reduction of 55% is achieved by the civil sector only, while without any constraint an important reduction is anyway registered, up to 45% for civil sector. Instead for the other non-ETS sectors the reduction in term of emission is limited to 36% in the constrained scenario. So, according to the result of the model, the civil sector has a higher economic potential on the emission reduction target than the other non-ETS sectors.

The buildings retrofit reaches the maximum allowed level of about 2% annual rate in both scenarios, so the heat demand in the two scenarios is the same but a different technological mix is obtained (Figure 5). The total space heating demand in the current scenario is equal to about 67.3 TWh and reaches about 58.0 TWh after retrofit. The reduction, is about 14%, is due to the refurbishment of the opaque envelope and to the substitution of windows (about 70% of energy saving considering both these two interventions). Natural gas boilers – the prevalent type of heating systems today – are still present in 2030 coupled with air conditioners, with a share of about 72% in the non-constrained scenario and 66% in the constrained scenario. In the constrained scenario the penetration of electric heat pumps achieves a value of about 10%. The comparison with the non-constrained scenario (5%) tells that the emission constraint makes electric heat pumps penetrate more. District heating represents about 18% of the total heat demand and it is always chosen by the model as a convenient option from the system point of view, regardless of the considered scenario and of the heat generation mix.

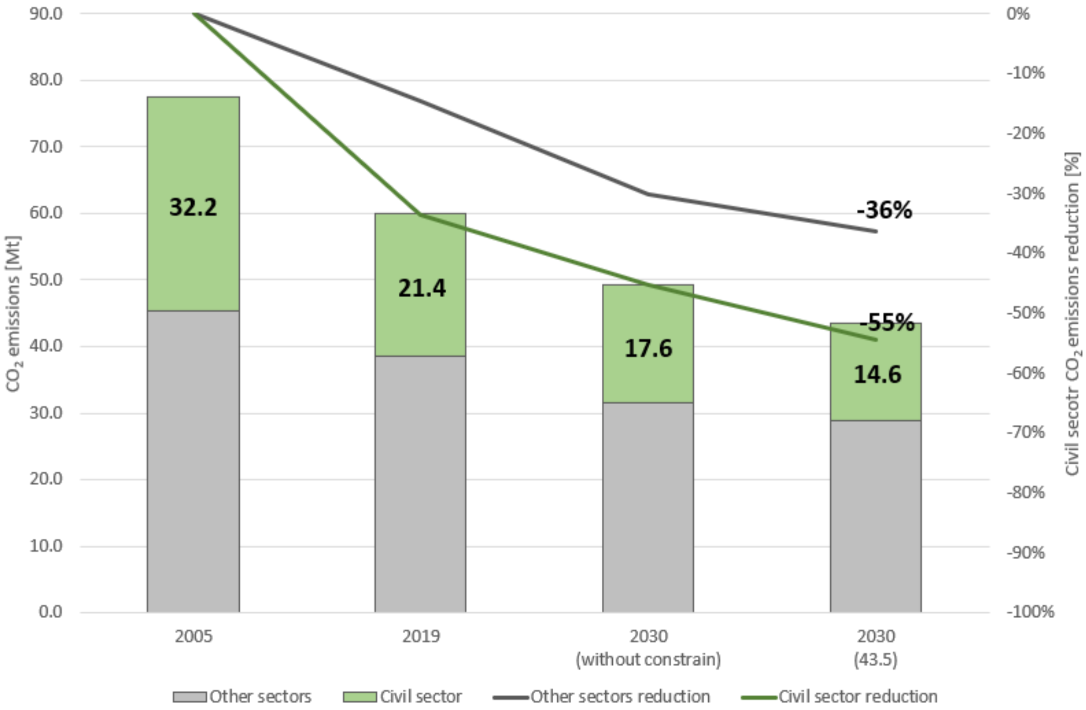

Figure 4. CO₂ emissions of the civil sector from the current level to 2030 considering two scenarios: (i) without constraint and (ii) with a constraint equal to 43.5 Mt (consistent with the Fit for 55 package) [Mt]

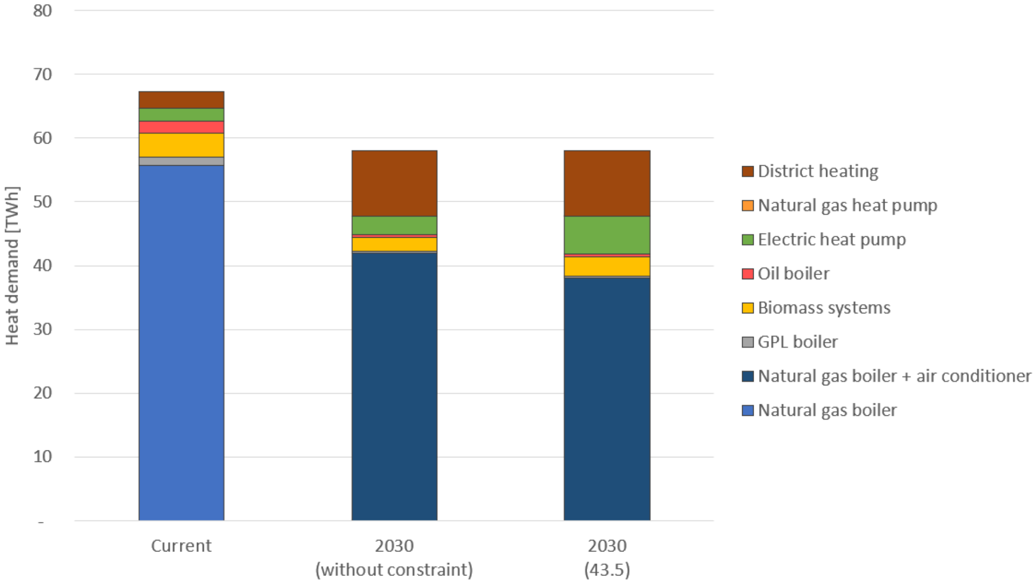

Figure 5. Civil sector space heating demand with the current technological mix and the mix resulting from the model considering two scenarios: (i) without constraint and (ii) with the constraint equal to 43.5 Mt (consistent with the Fit for 55 package) [TWh]

Figure 6 shows the comparison between the current technological mix and the mix obtained from the model with a CO_2 emissions constraint, with the detail of the buildings type: single-houses (current space heating demand 10.1 TWh and 8.7 TWh in 2030), apartments block with individual heating system (current space heating demand 30.5 TWh, 2030 space heating demand 26.2 TWh), apartments block with centralized heating systems (current space heating demand 10.0 TWh, 2030 space heating demand 8.6 TWh), tertiary buildings with individual heating systems (current space heating demand 3.4 TWh, 2030 space heating demand 3.0 TWh), tertiary buildings with centralized heating systems (current space heating demand 13.4 TWh, 2030 space heating demand 11.4 TWh). By analysing the technological mix resulting from the model, the most common heating systems in each building category are natural gas boilers (coupled with air conditioners), electric heat pumps, district heating and biomass systems (e.g. boilers, stoves, fireplace etc.). In particular, in the residential sector, the single-houses are prevalently served by natural gas boiler coupled with air conditioner (64% of the total heat demand in single-houses), followed by district heating systems (about 20%) and biomass boilers (10%), instead electric heat pumps satisfy only 5% of the total heat demand in single-houses; apartment blocks with individual heating system represents about 45% of the total heat demand of the civil sector with a technological mix made up of: 88% of natural gas boiler coupled with air conditioner, 7% of electric heat pump and 4% of biomass boilers; apartments blocks with centralized heating systems are prevalently connected to a district heating network (60%), followed by natural gas boilers coupled with air conditioner (24%) and electric heat pumps (5%). Tertiary buildings are prevalently served by centralized heating systems, about 80% of the total tertiary sector heat demand. Heating systems in tertiary buildings are made up of natural gas boilers coupled with air conditioners (51% in centralized systems, 46% in individual systems), district heating (30%, only in centralized systems) and electric heat pumps (12% in centralized systems, 46% in individual systems).

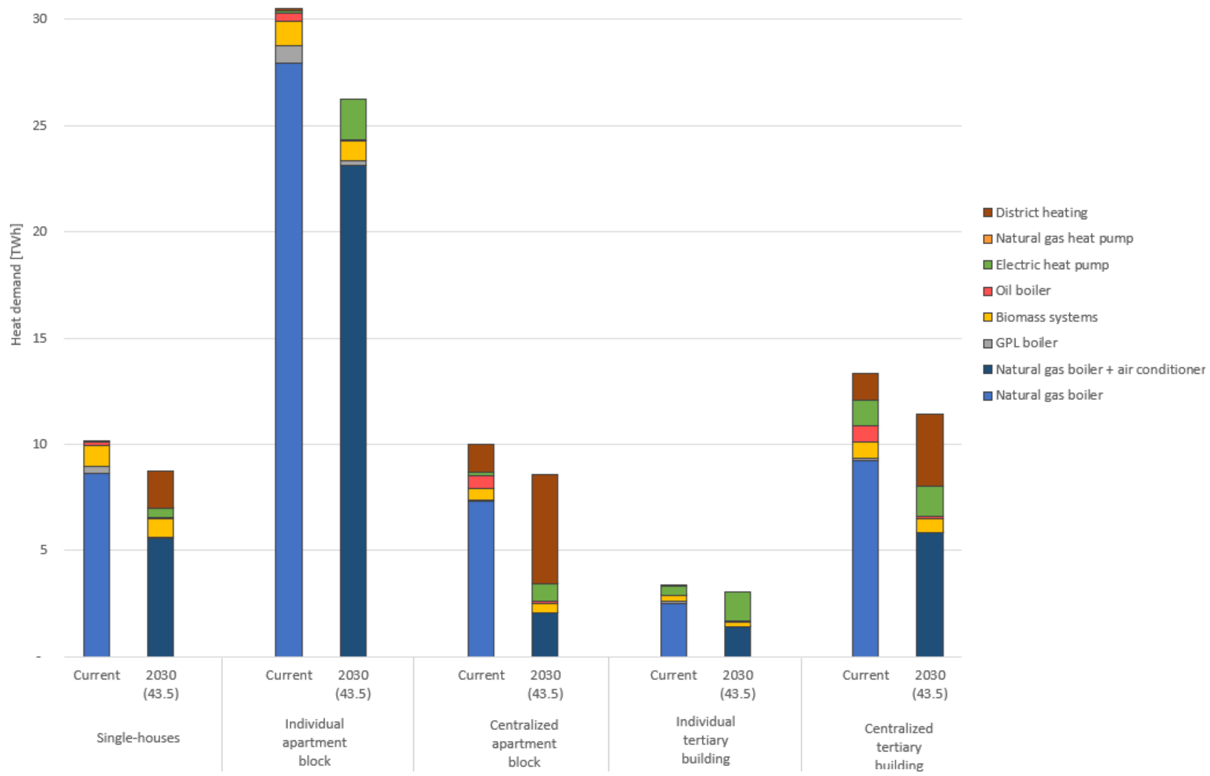

Figure 6. Civil sector space heating demand divided into the different buildings' typologies with the current technological mix and the mix resulting from the model considering the Fit for 55 package constraint [TWh]

The following maps show the detail of the optimal technological mix in each considered area, for each considered type of building. In particular, it can be seen that:

- Figure 7: in single houses natural gas boilers coupled with air conditioners are prevalent in most of the areas with a penetration between 35-91%. District heating systems are prevalently located in the central area of the region with a maximum penetration of 31% in the area of the municipality of Milano (3b). The range of district heating penetration is between 0-31%. Biomass systems are prevalently located in the northern areas with a penetration between 2-45%. A penetration of natural gas heat pump can be notice in only one area (1b) with a share of 12%.

- Figure 8: in apartments served by individual heating systems the technological mix is prevalently composed by natural gas boilers coupled with air conditioners (61-91%) and electric heat pumps (2-8%) in each area, with some biomass systems in the northern areas (1-20%).
- Figure 9: in apartments served by centralized heating systems district heating has an important penetration in some areas with a maximum value of 81% in the area around Lodi (4b), followed by 76% in the area close to Brescia (3d) and 71% in the area around Milano (3b). As in the other type of residential buildings, biomass systems are prevalently in northern areas (1-31%). Electric heat pumps are quite homogeneously distributed through the territory with a penetration between 1-13%, lower penetrations refer to the northern areas of the region. A penetration of natural gas heat pump can be notice in the same area of single house (1b) with a share of 12%.
- Figure 10: tertiary buildings heating demand is prevalently satisfied by natural gas boilers coupled with air conditioners for about 18-80%, by electric heat pumps with a very important role in this type of buildings (10-75%) and by biomass systems for about 1-45% with the highest value in the northern areas of the region (1a 49%, 1c 40%, 1b 19%).
- Figure 11: district heating has a lower penetration in tertiary buildings (0-39%) than in apartments block while natural gas boilers coupled with air conditioners has higher share (36-81%) than in apartments block. Electric heat pumps have share between 2-21%.

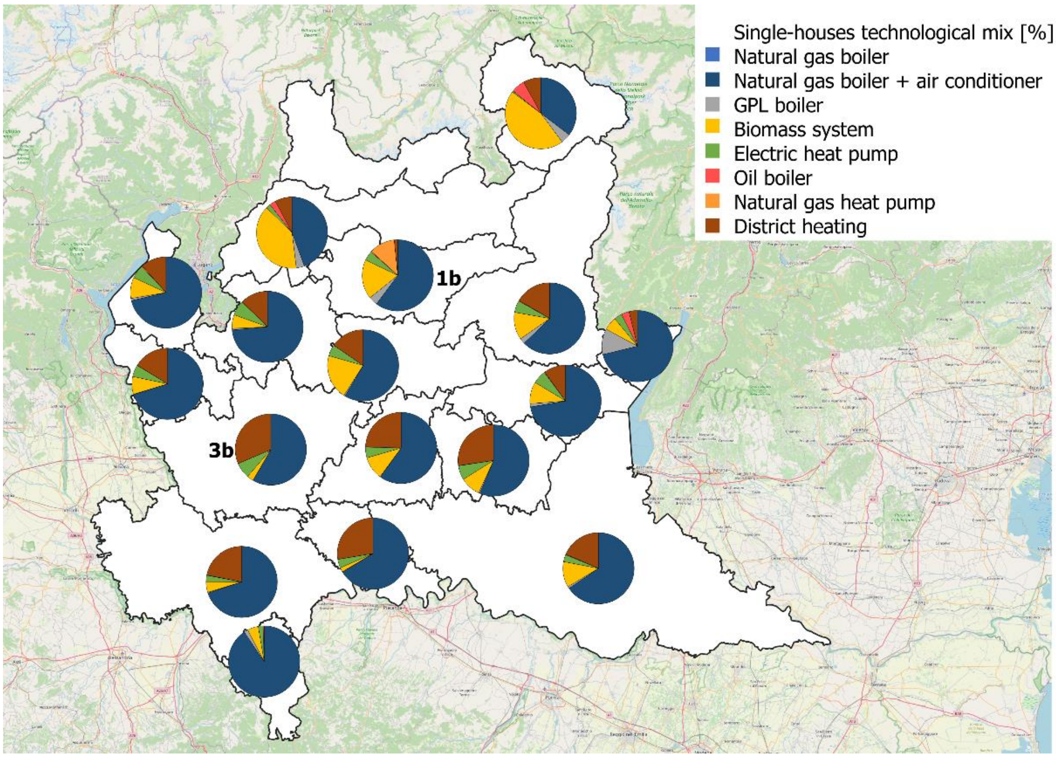

Figure 7. Single-houses technological mix in 2030 with the total emissions constraint equal to 43.5 Mt with the detail of the 17 areas [%]

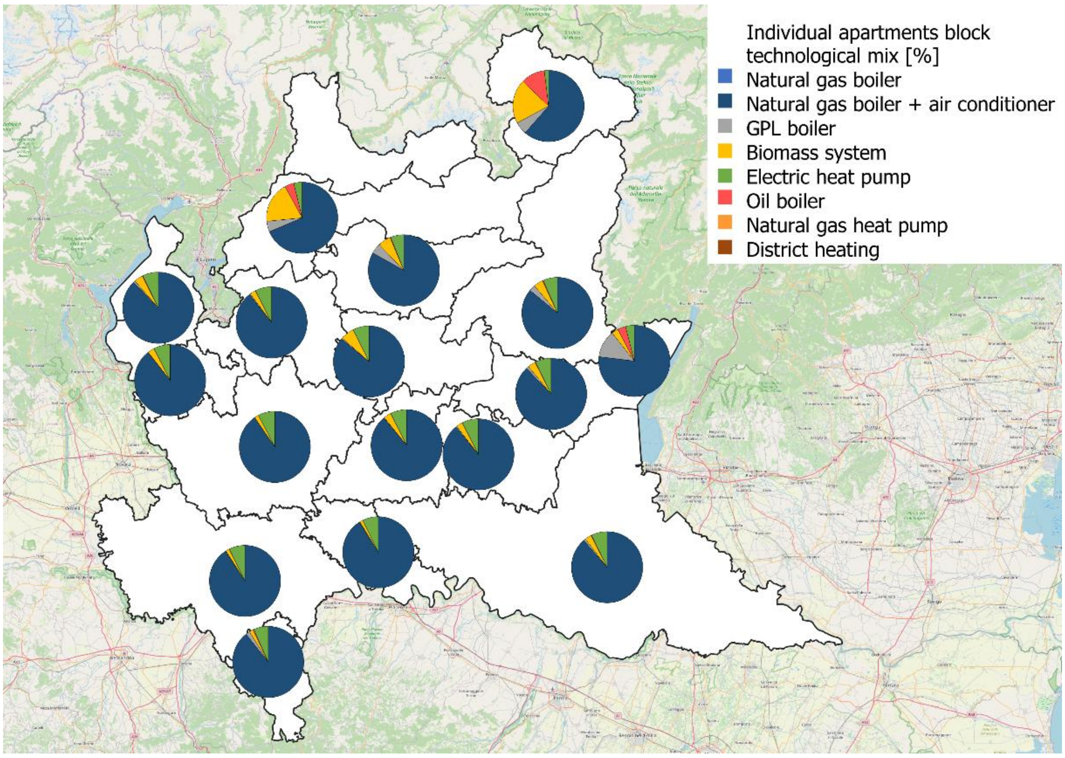

Figure 8. Apartment blocks with individual heating system technological mix in 2030 with the total emissions constraint equal to 43.5 Mt with the detail of the 17 areas [%]

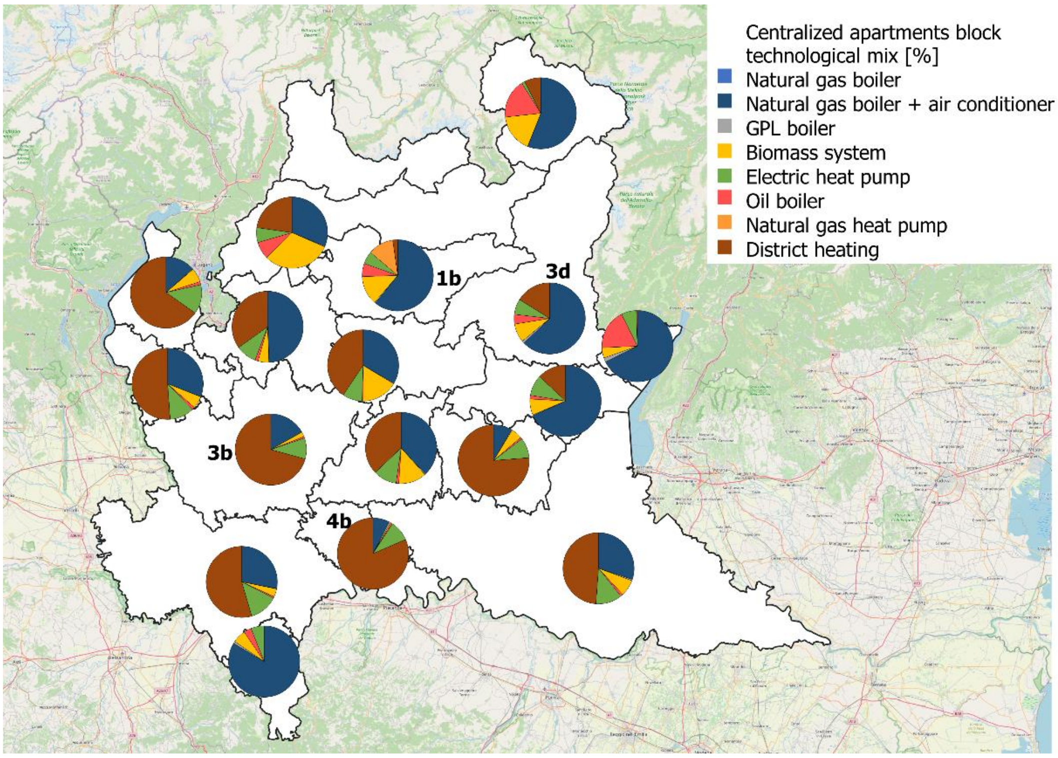

Figure 9. Apartment blocks with centralized heating system technological mix in 2030 with the total emissions constraint equal to 43.5 Mt with the detail of the 17 areas [%]

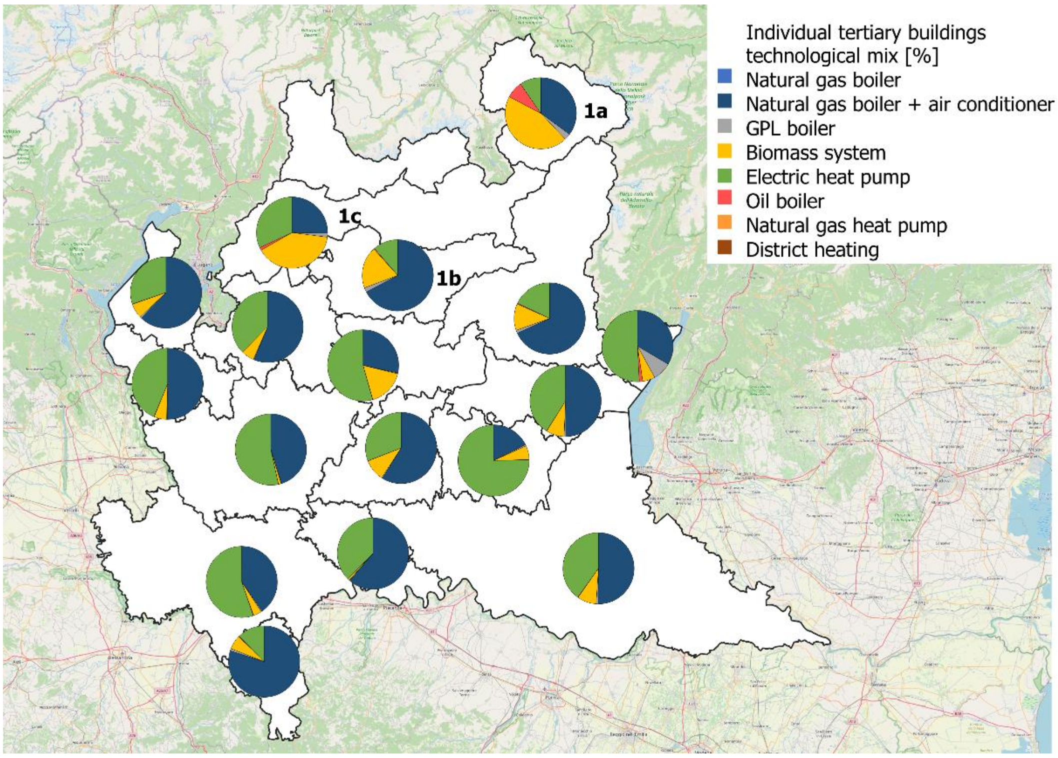

Figure 10. Tertiary buildings with individual heating system technological mix in 2030 with the total emissions constraint equal to 43.5 Mt with the detail of the 17 areas [%]

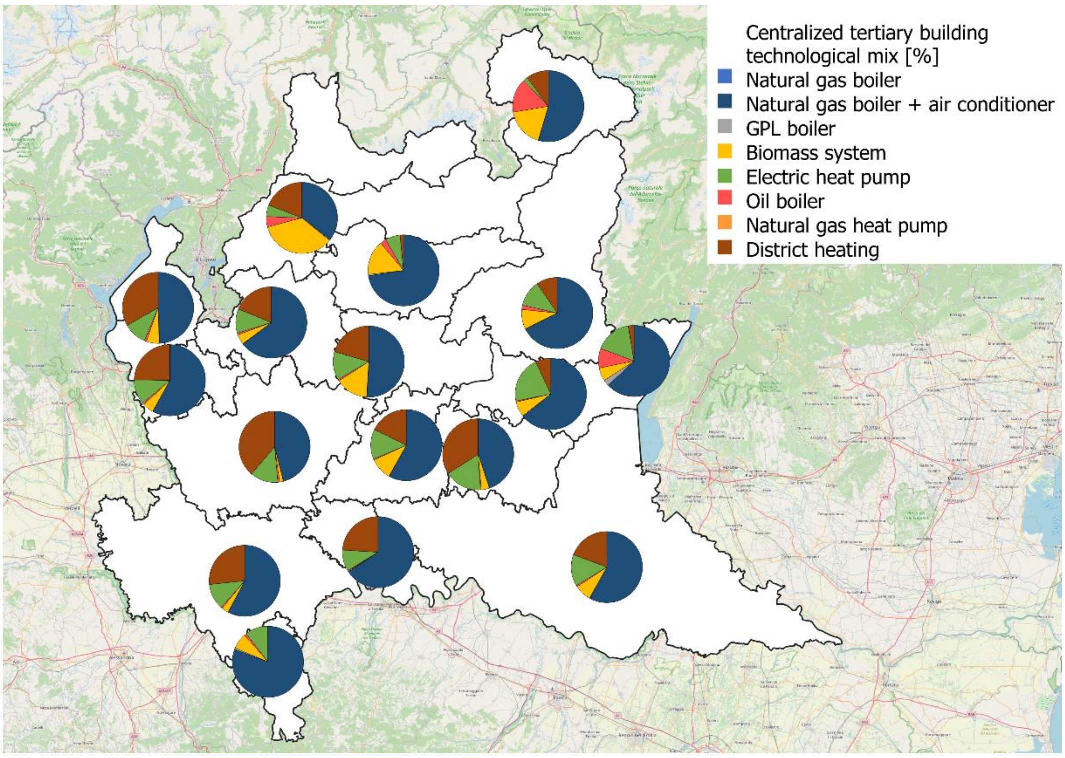

Figure 11. Tertiary buildings with centralized heating system technological mix in 2030 with the total emissions constraint equal to 43.5 Mt with the detail of the 17 areas [%]

4. Conclusions

This work aimed to define and compare the optimal technological mix for the civil sector under different CO_2 emission constrained scenarios. The results showed that the specific sector, compared to all the other non-ETS sectors, has an important role on the achievement of the overall target. Achieving in real life the mix suggested by the model is a hard challenge. In fact, due to the high emission reduction target, a high rate of substitution of current systems with technologies which exploit renewable sources or with a high efficiency is considered and actually required by the model. The difficulty of the application of the results of the model to the real life is also due to the people behavior, not considered in the model. Natural gas boilers still result the main technologies in buildings with individual systems and in single houses (mostly coupled with air conditioners also used as heat pumps). The still high dependence of the system on natural gas (mostly due to boilers) is very much linked to the refurbishment rate, which in turn limits the installation of heat pumps. In residential buildings with centralized heating systems district heating achieves important penetrations, in particular in specific areas in the center of the region. Electric heat pumps result quite homogeneously distributed through the region in residential buildings, while in the tertiary sector they have an important role for individual heating systems. The natural gas heat pump is present only in one area for single-houses and apartments block with centralized heating system. Sensitivity analysis show however that they have an important role in the technological mix with an increase of natural gas price and most stringent emission constraint. This technology is important to achieve a higher efficiency and lower emissions in areas where refurbishment is difficult. The envelope retrofit is always chosen by the model achieving the maximum considered potential. It is also the main intervention that helps the decarbonization process, so an increase of its value can help to have a cheaper and important decarbonization of heating sector.

This work can be a starting point for policies and measures that, based on numerical analysis, aim at achieving emission reduction target in the region. By changing the input values, the model can be applied to other contexts as well. Further developments of the model could improve the temporal resolution of one year and consider the transition period towards the target year.

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