Drivers of energy transition of Italian residential sector

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In the view of the needed energy transition, the work aims to evaluate the potential electrification of the Italian building sector, identifying the possible drivers towards its realization and exploring possible policy strategies that could push it. The work is part of the "Electrify Italy" project, developed by Politecnico di Torino and Massachusetts Institute of Technology, in cooperation with Enel Foundation.

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The current energy paradigm is not sustainable, being largely dependent on fossil fuels. Therefore, a transition of the actual energy system is strongly desired, aiming to overcome its limits in terms of pollution, energy efficiency, optimal resource allocation and consumption. Nowadays, electrification is perceived as a possible way of transitioning the current system towards a more sustainable one, allowing higher energy efficient consumption at demand side and boosting the spread of renewables sources at production level.

Buildings are responsible for more than one third of total primary energy consumption and emit around 36% of total greenhouse gas (GHG) emissions in the atmosphere [1]. Therefore, the role of the building sector in the realization of the advocated transition is crucial, and strong efforts still need to be undertaken at both private and public sides. Looking at the EU stock characteristics, most of the built volume is residential and old [2], thus asking for retrofit interventions and appropriate policy measures able to foster its transition. Deeping on Italy, the building sector in 2017 consumed approximately 43% of total final energy consumption and emitted 39% of total Italian emissions, with the residential sector alone accounting for around 22% [3].

Looking at the Italian stock characteristics, residential buildings account for almost 90% of the built volume [4], and they are less electrified than commercial ones (electricity represents 18% and 51% of the final energy consumptions of the residential and non-residential buildings, respectively), demonstrating that the highest potential for electrification stands in the residential sector. Here, the most energy-consuming services are space and water heating, which represent roughly 80% of the total energy consumption [3], besides being the less electrified services, thus having the highest potential for electrification. Starting from these figures, the work is intended to explore the potential electrification of the Italian residential building sector, starting from existing technologies and identifying the possible drivers towards its realization. Moreover, the analysis wants to identify possible policy strategies that could push the electrification of the residential buildings, exploring innovative elements of price mechanisms and market dynamics.

Method

The study aims to compare alternative technological solutions for space and water heating in case of a retrofit intervention, in order to understand the most important factors influencing building owners' choices towards electric technologies. Indeed, when dealing with future diffusion of electric technologies, the main issues are costumers' choices and market directions. From the costumer point of view, it is fundamental to understand which could be the technologies that they are willing to choose, while from the market standpoint, it is worth exploring how market mechanisms and policies will realistically push costumers' choices. The work identifies two possible drivers of the electrification process, at private and public sides. Financial convenience and attractiveness are defined as the main drivers at private side, and they are addressed in terms of global cost, a financial parameter usually used to compare different alternatives in retrofit interventions. Its calculation accounts for the initial investment cost and the annual costs (discounted at the present value with a constant interest rate), including maintenance and energy costs [5]. In this study, global cost is defined per each alternative over a 20-years period (lifetime of typical heating systems) and existing incentive mechanisms (Ecobonus and Conto Termico 2.0) are added to the formula, discounted at the present value. This index allows to estimate the financial convenience of a technology over other competing ones, since it combines all the expenses borne by the building owner and, thus, it could represent a relevant benchmark for making investment decisions. From the public standpoint, instead, bearing in mind the ambitious targets conceived for the building sector in terms of emissions reduction (90% reduction by 2050 with respect to 1990 levels [6]), policy makers will realistically define measures capable of forcing the market towards the adoption of low-carbon solutions, making them more financially attractive for the investors. CO_{2eq} emissions caused by the adoption of a certain technology is thus selected as a driver for future electrification at public side. Moreover, PM emissions are accounted too, when comparing the alternative technological options. Indeed, due to the recent concern on air pollution, especially in urban areas, it is likely that PM is going to be a criterium to control in future energy planning.

The work was structured according to the following steps:

- Characterization of the current residential building stock through a reference building approach;
- Identification of the technological alternatives;
- Environmental and financial assessment of each alternative.

To characterize the current residential building stock, whose thermal uses are the focus of this work (see "Introduction"), the reference building approach [7] is deployed. The Italian building stock is divided into a set of representative reference buildings, according to different typologies (Single-Family Houses, SFH, and Multi-Family Houses, MFH), periods of construction ("before 1980", "1981-2000", "after 2001"), and locations (5 geographical zones are identified: North-West, North-East, Centre, South and Islands). Moreover, the RBs are divided into urban (67% of the total floor area) and extra-urban buildings (33% of the total floor area), where urban areas are defined as municipalities with more than 10,000 inhabitants [4]. Each RB is characterized by specific envelope and system characteristics according to TABULA database [7]. Energy needs for space and water heating are defined by means of quasi steady-state simulations, while energy consumptions are calculated assuming suitable generation efficiencies.

When considering a retrofit intervention, the model allows only three alternatives for space heating (condensing gas boiler, biomass boiler and electric heat pump) and four options for water heating (condensing gas boiler, biomass boiler, electric boiler and electric heat pump). Both biomass boiler and electric heat pump, for the sole space heating, need the use of a thermal storage, which cost is added to the global cost formula.

Global costs (private side driver) and emissions (public side driver) are calculated for 2030 and 2050, in order to evaluate the expected evolutions of the competitiveness of the technologies in future years, based on different assumptions. Energy prices are forecasted based on IEA projections [8], while CO_{2eq} emission factors for electricity are varied according to the evolution of the power generation mix predicted in the "Electrify Italy" project [9]. The study is developed considering the following assumptions:

- Restriction of biomass use in urban environment, in accordance with existent environmental policy constraints (Some Italian regions (i.e. Piemonte, Lombardia, Emilia Romagna) have imposed constraints to the installation of biomass heating systems in urban areas, due to local air pollution issues.);
- Incentives mechanisms fixed as in 2015 (Ecobonus and Conto Termico 2.0);
- Introduction of non-progressive concessional tariff for SFH with heat pumps as sole space heating system in the global cost calculation.

Results & Discussion

Customers' choices are a key factor in the process of electrification of the residential sector and are driven by several factors, among which the most important one is the financial convenience, here addressed in terms of global cost. In Italy, electric technologies, even if already competitive in the market, are still slightly disadvantaged, due to the higher investment costs and energy prices for electricity. Nevertheless, electric heat pump has a strong advantage with respect to its competitors, due to the possibility of providing both space heating and cooling. For this reason, in order to compare the solutions on equal terms, the cost for a multi-split air conditioning system is added to the global cost for gas technologies (in terms of investment cost) as an opportunity cost. This modification is applied only in urban areas, where the impact of air-conditioning is significantly stronger, due to the higher temperatures and the worse outdoor air quality than in extra-urban context. An example of global cost calculation is here reported for an RB (MFH built before 1980, located in North-West) and for the space heating service. In urban area, where the competition exists between gas and electric technologies (being biomass excluded), the extra global costs of heat pump is always lower than 15%; in extra-urban context, biomass is still slightly convenient in 2030, while in 2050 energy costs projections clearly disadvantage it with respect to heat pump.

However, when considering the environmental impacts, electric technologies are the most environmentally performing. **Figure 2** compares the considered technological solutions for the same RB based on their emission footprints (in terms of direct CO_{2eq} and PM10 emissions), and thus showing how heat pump represents the best environmental compromise. Conversely, gas technologies are the worst in terms of CO_{2eq} emissions, while biomass is the highest PM10 emitter.

The paper aims also to explore in which direction the market and the policy context might push costumers' choices towards electrification, by investigating how innovative elements in terms of market regulation mechanisms and pricing models can impact on the global cost results. In particular, the study reports the variations of the delta global costs between electric and gas technologies for the urban area and between electric and biomass technologies for the extra-urban context caused by the introduction of these measures. The first measure ("HP tariff") considers the extension of the non-progressive concessional tariff for electricity to heat pumps installed in MFH for space heating and in both SFH and MFH for water heating (excluded in the current regulation). The second analysis ("Constant price") explores the influence of energy prices, analysing an ideal situation in which

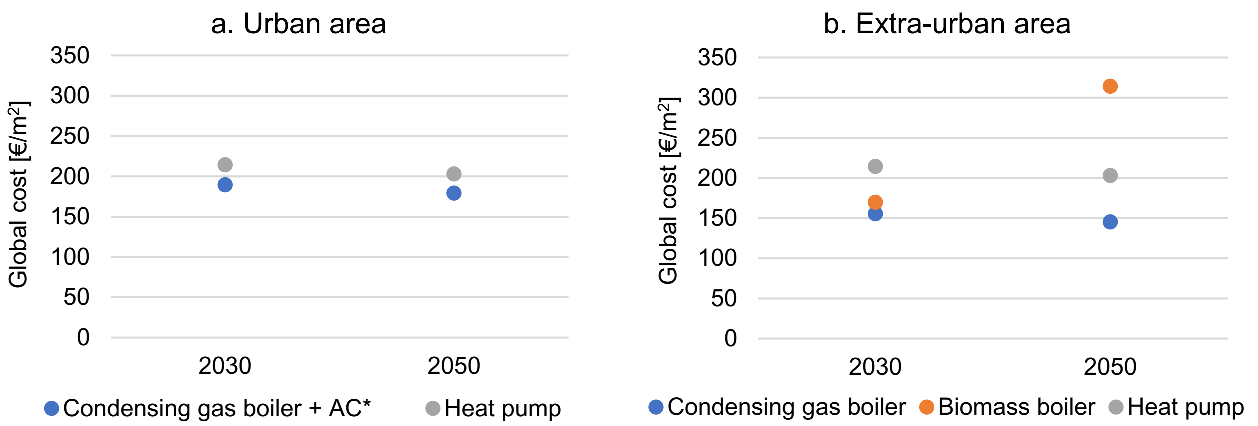

Figure 1. Global cost in 2030 and 2050 for MFH < 1980 North-West for space heating: a. urban area; b. extra-urban areas.

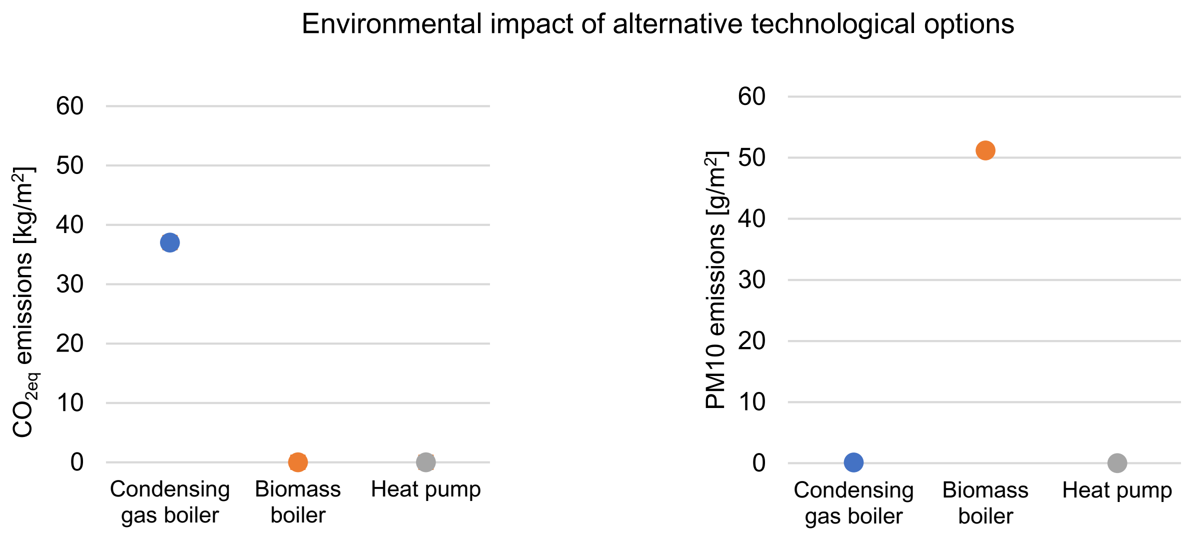

Figure 2. Environmental performances (in terms of direct emissions) of the technological options for MFH < 1980 North-West – space heating: a. CO_{2eq} emissions; b. PM10 emissions.

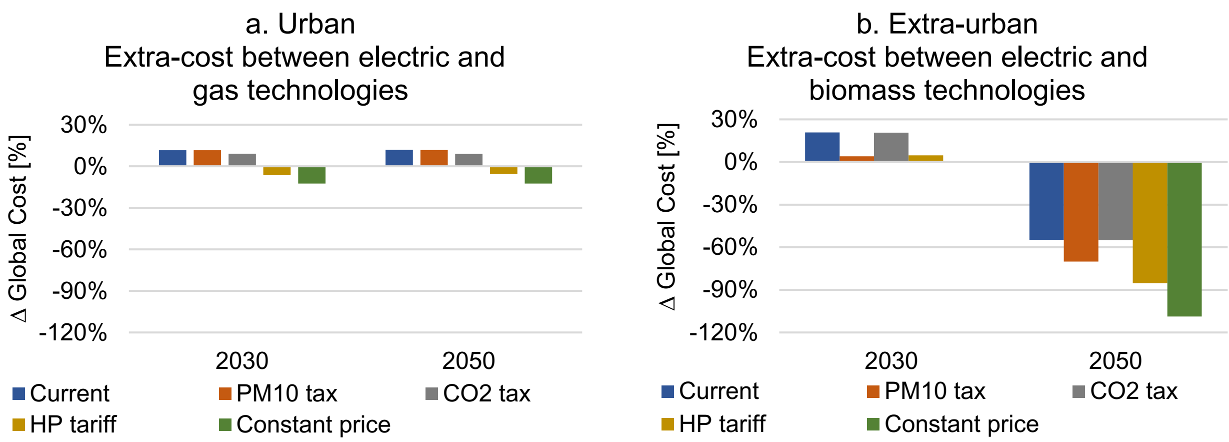

Figure 3. Delta global costs of heat pumps with respect to the competing technological option for MFH < 1980 North-West – space heating: a. gas-heat pump competition (urban); b. biomass-heat pumps competition (extra-urban).

gas and electric prices are kept constant to current values. Finally, the introduction of environmental taxes as market regulation mechanisms is investigated as a policy attempt to face the air pollution issue and to force the achievement of the emission reduction targets at building scale. Two measures are evaluated, considering the adoption of a taxation on CO_{2eq} ("CO_2 tax") and on PM10 ("PM10 tax") emissions for space and water heating systems.

In urban area, competition exists only between gas and electricity, due to the exclusion of the biomass. In this context, the PM taxation has a marginal impact on the global cost, conversely to the CO_2 taxation, which surely disadvantages gas. Still, environmental costs are not enough to make electric technologies competitive, thus asking for appropriate financial measures to facilitate its diffusion; indeed, both "HP tariff" and "Constant price" scenarios help reversing the results, advantaging heat pumps. In extra-urban context, environmental costs can push costumers' choices towards electric technologies; extra-costs of heat pumps with respect to biomass technologies reduce of almost 30% when adopting the PM tax, due to the high emissions caused by biomass combustion. Differently from urban area, financial measures have lower impact on results. However, it is worth noting that energy prices are among the most influencing parameters, as shown by the "Constant price" scenario in both contexts, meaning that the price model plays a key role in future diffusion of technologies.

Conclusions

The significant impacts that the building sector has on environment and society are forcing private and public stakeholders to find possible solutions for unlocking the transition of the entire sector towards a sustainable one, considering electrification as a possible solution. Focusing on the residential sector and on thermal uses (which are the least electrified services in buildings), the study aims to compare alternative existing technological solutions (condensing gas boiler, biomass boiler, electric boiler and electric heat pump) for space and water heating in case of a retrofit intervention, in order to understand the most important factors influencing building owners' choices towards electric technologies. Financial convenience is identified as the private side driver, while environmental protection (in terms of CO_{2eq} and PM emissions) is defined as the public side driver. Moreover, due to the role that market and policy dynamics play in the future transition of the building sector, the paper aims to explore in which direction the policy context might push costumers' choices, by investigating innovative elements in terms of market regulation mechanisms and pricing models. ■

Acknowledgment

The work is part of the project "Electrify Italy", developed by Politecnico di Torino and Massachusetts Institute of Technology, in cooperation with Enel Foundation [9].

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