Discussion Paper Series

A quantification of the costs and benefits of the "Green buildings" directive in two Italian regions

Discussion Paper n. 01/2025

Lorenzo Forni
Filippo Fortuna
Elena Giarda
Francesco Giovanardi
Demetrio Panarello

Fondazione GRINS
Galleria Ugo Bassi 1, 40121, Bologna, IT - C.F/P.IVA 91451720378
info@grins.it | comunicazione@grinsfoundation.it | fondazionegrins@pec.grins.it | grins.it

Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA | GRINS FOUNDATION

ISSN 3035-5567

A quantification of the costs and benefits of the "Green buildings" directive in two Italian regions

DP N. 01/2025
May 2025

This paper assesses the monetary costs of meeting the targets for 2030 and 2033 outlined in the EU Energy Performance of Buildings Directive (EPBD). The analysis focuses on two Italian regions and demonstrates that these costs are substantial. We employ open-source microdata on Energy Performance Certificates (EPCs) for the Lombardy and Piedmont regions, which provide information on dwellings' energy class and recommendations of the necessary retrofits to reach a higher energy class, as well as CO2 emissions and energy consumption. We estimate a total expenditure of €118.9 billion to take Lombardy's and Piedmont's residential stock to at least energy class D, which is 20.2% of the two regions' GDP and 5.6% of Italy's GDP. Understanding the balance of costs and benefits is crucial to evaluate the economic incentives for homeowners to adopt energy efficiency measures. Households are estimated to save yearly €3.3 billion in lower energy bills in the two regions, and CO2-equivalent emissions are estimated to drop annually by 6.9 million tons. While homeowners may internalise the private benefits, they are unlikely to account for the social benefits in terms of lower emissions. As a result, achieving the EPBD targets is likely to require public subsidies.

Keywords: Energy Performance Certificates (EPC); Energy Performance of Buildings Directive (EPBD); retrofit costs; energy efficiency.

JEL Classification: Q40; Q52; Q58.

Lorenzo Forni
Prometeia, Bologna, Italy
University of Padua

Filippo Fortuna
Prometeia, Bologna, Italy
Pompeu Fabra University, Barcelona, Spain

Elena Giarda
Prometeia, Bologna, Italy

Francesco Giovanardi
Prometeia, Bologna, Italy
University of Modena and Reggio Emilia

Demetrio Panarello
Prometeia, Bologna, Italy
Link Campus University, Rome, Italy

This study was funded by the European Union - NextGenerationEU, in the framework of the GRINS - Growing Resilient, INclusive and Sustainable project (GRINS PE00000018 - CUP D13C22002160001). The views and opinions expressed are solely those of the authors and do not necessarily reflect those of the European Union, nor can the European Union be held responsible for them.

Fondazione GRINS
Galleria Ugo Bassi 1, 40121, Bologna, IT - C.F/P.IVA 91451720378
info@grins.it | comunicazione@grinsfoundation.it | fondazionegrins@pec.grins.it | grins.it

1. Introduction

Buildings are the single largest energy consumer in Europe: in 2021, 42% of energy consumed in the EU was used in buildings, over one third of EU's energy-related greenhouse gases (GHG) emissions came from buildings and around 80% of the energy used by EU households was for heating, cooling and hot water (European Commission, 2024). Moreover, the EU's building stock is old, with 85% of buildings built before 2000, of which 75% have a poor energy performance. As for Italy, 55% of buildings were built more than 50 years ago and 28% of all residential dwellings display the lowest energy efficiency level. These figures highlight that the building sector is crucial to achieving EU's energy and climate goals, and for this reason numerous European countries are actively working towards decreasing the energy usage and associated GHG emissions of their residential sector. However, attention is required in designing fair policies and setting their timing, since there is evidence that climate change policies may be associated with increased income inequality (Bettarelli et al., 2024; Gatto et al., 2023).

To boost buildings' energy performance, the European Union established a legislative framework that includes the Energy Performance of Buildings Directive (EPBD) 2010/31/EU and the Energy Efficiency Directive 2012/27/EU. Together, the directives promote policies that will help: (i) achieve a highly energy efficient and decarbonised building stock by 2050, (ii) create a stable environment for investment decisions, and (iii) enable consumers and businesses to make more informed choices to save energy and money. Both directives were revised in 2018 and 2019, as part of the 'Clean energy for all Europeans' package. In 2020, the Renovation wave strategy, as part of the European Green Deal, set the objective to at least double the annual energy renovation rate of buildings by 2030. At the end of 2021, the European Commission (EC) adopted a major revision (recast) of the EPBD (the so-called 'Green buildings' directive), as part of the 'Fit for 55' package. This package is a core part of the European Green Deal, which aims to set the EU on a path towards net zero GHG emissions (climate neutrality) by 2050 (Panarello and Gatto, 2023). The 'Green buildings' directive is an important component of the package: it aims at accelerating building renovation rates, reduce GHG emissions and energy consumption, and promote the uptake of renewable energy in buildings, by focusing on the worst performing 15% of EU buildings.

Energy performance is measured by the Energy Performance Certificates (EPCs), which attribute an energy efficiency label to buildings on a scale from G (the least efficient) to A4 (the most efficient) based on buildings' overall energy consumption. According to the recast EPBD (to which we address as 'EPBD-2023' henceforth), all residential buildings had to achieve at least class E by 2030 and at least class D by 2033. However, in March 2024, the European Parliament approved a further revision of the EPBD (which we label 'EPBD-2024') allowing for some flexibility with respect to which buildings to target and which measures to undertake. Each Member State is now allowed to adopt its own strategy to reduce the average primary energy use of residential buildings by 16% by 2030 and by 20-22% by 2035. However, each Member State is subject to one constraint: at least 55% of the reductions must be achieved through the renovation of the worst-performing buildings.

As far as Italy is concerned, various steps were taken towards making the country's dwelling stock more energy-efficient, starting from the 1998 Budget Law that introduced tax credits on housing renovations ('Bonus casa'). In 2007, these tax credits were extended to include energy-efficiency retrofits ('Ecobonus'). In 2020, the so-called 'Rilancio' Decree, besides measures to support the economy during the COVID-19 pandemic, introduced a substantial policy intervention ('Superbonus') to pursue the energy saving and GHG emissions reduction targets outlined in the 2019 Integrated National Energy and Climate Plan (PNIEC). The 'Superbonus' allowed for a 110% tax credit on energy efficiency renovations, provided that the building improved its energy performance by two classes.[1] The 'Superbonus 110%', together with the 'Façade bonus', had a cost of around €170 billion over the period 2020-2023, but estimates show that about one fourth of this amount (€45 billion) was a deadweight loss since the renovation works would have been carried out regardless of the incentives (Accetturo et al., 2024).[2]

The aim of this paper is to quantify the costs and benefits associated with the implementation of energy efficiency measures in residential buildings in the North of Italy, by looking at the EPBD-2023, which, at the time of writing the paper in 2023, was the directive being discussed by the

[1] For an overview of the energy efficiency measures implemented in Italy, see De Blasio et al. (2024).

[2] The relief consists of a tax deduction, to be split into ten constant annual instalments, equal to 90% of the expenses incurred in 2020 and 2021, and 60% of the expenses incurred in 2022, for interventions aimed at the restoration of the external façade of existing buildings.

European Parliament and the Council. Specifically, we provide an estimate of the costs of renovating low-efficient buildings to reach class E and then at least class D, and the associated benefits in terms of reduced CO2 emissions and energy expenditure. This is particularly relevant since many European countries are taking action to contain their residential sector's energy usage and CO2 emissions. Furthermore, the recent consensus on the Directive at the European level underscores the growing importance and commitment to enhancing energy efficiency in the housing sector.

We computed the energy savings implied by the EPDB-2023 and checked whether they are aligned with the new requirements approved by the European Parliament in March 2024 in the EPBD-2024. We find that if all the dwellings of the national residential stock reached at least class D, the implied reduction of energy use would overshoot the 20-22% requirement, reaching 27.9%. In our analysis we propose a strategy to meet the EPBD-2024 requirement.

To perform our analysis, we employ novel open-source and almost unexploited microdata on EPCs provided by two Italian regions, Lombardy and Piedmont, covering the periods 2015-2022 and 2015-2023, respectively. We limit our work to these two regions since Italy's National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) does not provide microdata on Energy Performance Certificates (EPCs). Despite our analysis is limited to this area, it is of relevance for policy makers and researchers in the field since the two regions together gather one fifth of Italy's overall dwellings, are inhabited by about one fourth of the country's population and produce around one third of the national GDP.

The datasets contain information on dwellings' energy-related characteristics, such as performance class, global non-renewable energy performance index, global renewable energy performance index, reference standard non-renewable energy performance index, CO2 emissions, dispersion surface, and annual consumption of all types of energy. They also provide other pieces of information, such as location, usable heated surface, usable cooled surface, number of properties in the building, construction year, and climate zone. The data refer only to properties with an EPC, that is, those that have been sold, rented out or have undergone major renovation, as set by the legislation.

We contribute to the literature by employing two regional EPCs datasets, unexploited by the literature on energy efficiency and retrofit costs so far. One of the features of the data are the retrofit recommendations provided by the domestic energy appraiser filling in the EPC. The typical recommendation contains: (i) a brief description and categorization of the recommended retrofit, (ii) the energy performance class and the global non-renewable energy performance index that the dwelling would obtain should the recommendation be implemented, (iii) an estimated return year of the investment, i.e. how many years of energy savings are needed to repay the investment required to implement the recommendation, and (iv) the performance class and the index that the dwelling would achieve should all the provided recommendations be implemented.

Our simulations show that the estimated total cost of taking Lombardy's and Piedmont's residential stock from classes G/F/E to at least class D is €118.9 billion, which corresponds to 20.2% of the two regions' yearly gross domestic product (GDP) and 5.6% of Italy's GDP. The size of this figure reveals that the financial burden of the EPBD-2023 could not be borne by the private sector only, but that it would require government intervention. As for the benefits, we estimate annual savings in energy (electricity and gas) expenditure of €2.5 billion and €0.9 billion in Lombardy and Piedmont, respectively, while CO2-equivalent emissions are estimated to drop yearly by a total of 6.9 million tons (5.2 million tons in Lombardy and 1.7 million tons in Piedmont).

The paper is organised as follows. Section 2 reviews the literature. Section 3 describes the data. Section 4 outlines the simulation exercise (methodology and results), Section 5 discusses some policy implications and Section 6 concludes with a summary of the main findings.

2. Literature review

There is a wealth of literature on the energy efficiency of buildings, which develops along a few strands. One deals with technical aspects of EPCs, such as the work of Khayatian et al. (2016) that applies neural networks for evaluating energy performance certificates of residential buildings in the Lombardy region of Italy. Another example is the work of Gouveia and Palma (2019) in which, besides presenting descriptive analysis, the authors compute the theoretical and actual heating and cooling final energy consumptions to analyse the energy performance gaps of Portugal's dwelling stock. The analysis performed by Streicher et al. (2018) allows the estimation of a thermal performance level of archetype buildings and their respective building elements as well as of the heating systems.

Another strand of the literature is mainly descriptive and presents first findings on the data available to better understand the energy efficiency of the building stock of the countries analysed. Daskalaki et al. (2013) provide an insight of the energy performance of buildings in Greece, where the most widespread EPC class is the lowest one and older buildings have the poorest energy performance in all climate zones. As for Spain, Gangolells et al. (2016) find that most of the residential buildings were in class E, and that single-family houses were found to use more energy on average than individual apartments; moreover, modern buildings consume less energy, as expected. For Sweden, Hjortling et al. (2017) find that climate zones have less impact on energy consumption than the type of building but dwellings in warmer climate zones generally have slightly lower energy consumption than those in colder ones.

The investigation of the determinants of EPCs is the object of another research line. An example is the work of Otsuka and Goto (2015) for Japan who apply a stochastic frontier model to estimate the energy demand function and analyse the levels and determinants of energy efficiency. The same methodology is employed by Otsuka (2018) who finds that population density and electrification rate foster energy efficiency in Japan. Trotta (2018) employs a probit model to investigate the dwelling-related and households characteristics influencing energy efficient retrofit investments in England's residential sector. Another example is the work of Dolsak (2023) who presents a detailed literature review and bibliometric analysis of the determinants of energy-efficient retrofits and highlights that the most influential factors are thermal comfort, energy cost, sustainable retrofit and households' behaviour change with respect to implementing energy-efficient retrofits. Billio et al. (2024) employ machine learning techniques to investigate the determinants of residential building energy efficiency in Italy (Lombardy region) and the UK (Greater London area): they find that factors related to heating systems and insulation materials play the most relevant role in determining building's efficiency.

In general, increasing buildings' energy efficiency would prevent property depreciation and possibly enhance households' housing wealth. The improvement of energy efficiency is also valuable to tackle climate risk, especially when related to extreme weather events such as spikes or slumps in temperatures. More in general, working towards the improvement of energy efficiency relates also to climate adaptation, which deals with other extreme weather events as well such as floods (see, for instance, Hennighausen et al., 2023) and destructive storms and sea-level rise (e.g., Bunten and Kahn, 2017).

Scholars have extensively studied the relationship between EPCs and house prices. With increasing awareness and concern about energy performance, EPCs are expected to positively influence consumers' choices and shift their preferences towards more efficient buildings. Most studies employ hedonic regressions, while others extend the analysis by applying spatial models. Perhaps the first study in this direction is that of Berry et al. (2008) for Australia who apply a hedonic regression to investigate whether house energy ratings affect prices. Ratings are found to be positively associated with price and to have a significant relationship. Brounen and Kok (2011) implement a Heckman model to Dutch data and find that private consumers use the information disclosed by the energy label and take the relative energy efficiency of their prospective home into account when making investment decisions. Cerin et al. (2014) find that EPCs contribute to property price premiums in Sweden. Similar results are found for other countries such as Fuerst et al. (2013) and McCord et al. (2020a and 2020b) for Wales, Droutsa et al. (2016) for Greece, and Taruttis and Weber (2022) for Germany. Mudgal et al. (2013) perform a comparative analysis on Austria, Belgium (Flanders, Wallonia, Brussels-Capital), France (Lille, Marseille), Ireland, UK (Oxford, South-East). The price (sale or rental) of an individual property is explained as a function of a series of characteristics, such as size, number of bedrooms/bathrooms and location, in addition to the EPC class. The analysis of property transactions points to energy efficiency being rewarded, except for Oxford that displays a negative relationship.[3]

There is very limited evidence for Italy, since publicly available data on EPCs is very scarce – even more so on data linking EPCs and prices. Fregonara et al. (2017) assess the impact of EPCs on the real estate market of Turin, a city in the Northwest of Italy. They employ a hedonic price model and find that low EPCs are priced in the market although EPC labels explain only between 6% and 8% of price variation. In addition, a second full hedonic model, which includs apartment characteristics, reveals that EPC labels have no significant impact on prices. The study of Bisello et al. (2020) focuses on the real estate market of Bolzano, a city in the Northeast of Italy, and finds a price premium of around 6% on moving from the worst to the best energy efficiency class. Moreover, they also uncover spillover effects to nearby properties. Both hedonic price regressions and spatial models are employed. Moreover, there is evidence that properties more than 40 years old that have not been renovated have an average price per square meter that is 25% lower than

[3] For an extensive literature review, see for instance Bisello et al. (2020).

that of dwellings built after 2000 (Immobiliare, 2014). Recently, Loberto et al. (2023) extend the analysis to the whole of Italy by employing privately owned listing data and find that dwellings with the highest energy label have an average price premium of 25% compared with the worst energy-performing ones, but that the premium is highly variable across the country. Giarda and Panarello (2025) employ EPCs microdata of three Italian regions (Emilia-Romagna, Lombardy and Piedmont) and estimate a set of models whose results reveal the existence of an energy-efficiency price premium in the three regions, with significant differences among them and heterogeneity along the price distribution.[4] In our paper, when accounting for the private benefits of building retrofitting, we include only the savings from lower future energy bills and exclude estimates of the price premium. This approach assumes that most of the gains from retrofitting are derived from the net present value of reduced energy costs, which should, in turn, be reflected in higher property prices. To avoid double counting, we focus exclusively on the first of these two dimensions.

Finally, there is limited evidence on the quantification of the costs implied by the EPBD. Politecnico Milano et al. (2024) estimate that the reduction of primary energy consumption on the 43% of class-G residential buildings will involve an investment of €93 to €103 billion by 2030 and that the cost would rise to €170 billion if also higher energy class dwellings were involved. Instead, Borgarello et al. (2023) estimate an overall cost of €400 billion for the entire country to bring low-efficient buildings to class E and class D, under the hypothesis that households switch from a gas heater to a heat pump to move from class G to class E, and that they install solar panels to move further to class D.

3. The data

To perform the analysis, we employ the only publicly available microdata on Italian EPCs referring to two Northern Italian regions: Lombardy and Piedmont.[5] Our analysis is restricted to these two regions because they are the only ones having made EPCs microdata publicly available through

[4] Another line of research deals with the relationship between energy poverty and buildings' energy performance (see, for instance, Fabbri and Gaspari (2021) and Camboni et al. (2021) for the Italian case).

[5] The data are provided by CENED (https://www.cened.it/opendata-cened-2.0, accessed 01/02/2023) for Lombardy and Regione Piemonte (https://www.dati.piemonte.it/#/catalogo, accessed 01/02/2023) for Piedmont.

their open data portals. We are aware that the regional focus limits the ability of our study to extend our findings to the entire country, but unfortunately ENEA's data portal SIAPE does not provide EPCs microdata but only aggregate-level information.[6] However, in Section 4.1 we provide an estimate of the overall cost for the entire country. Despite this data limitation, our analysis is of relevance for policy makers and researchers in the field since around one fifth (19.6%) of Italy's dwellings are located in the two regions, their population represents almost one fourth (23.7%) of the total and the area produces just below one third (29.3%) of national GDP.

The datasets cover the period 2015-2022 for Lombardy and 2015-2023 for Piedmont and we concentrate on residential buildings. After filtering out non-residential dwellings, the original datasets contain 1,182,468 observations for Lombardy and 474,935 for Piedmont, which represent 21.1% and 17.0% of the total residential units in the two regions, respectively.[7] These low percentages highlight the fact that most buildings lack any information on their energy efficiency level, making it hard for policy makers to evaluate the cost and the impact of climate change policies. An attempt to fill in this gap is provided by Braggiotti et al. (2024) who apply a machine learning approach to a privately-owned dataset to predict EPCs in Italy.

In addition to the energy performance class, both datasets contain a wealth of information on the buildings' characteristics, such as location (address and other cadastral information), usable heated surface, usable cooled surface, number of properties in the building, construction year or period, and climate zone.[8] Energy-related information comes from the energy class, the global non-renewable energy performance index, the global renewable energy performance index, the reference standard non-renewable energy performance index, CO2 emissions, dispersion surface,

[6] An exception is the work of a group of researchers from ENEA – Pagliaro et al. (2021) – who had access to a sample of 2,000,000 EPCs extracted from the Information System on Energy Performance Certificates (SIAPE). However, data limitation extends beyond this context, reflecting a persistent gap in the availability of detailed qualitative and quantitative data on sustainability and energy consumption patterns (Gatto and Panarello, 2022).

[7] The percentages are based on 2021 Census data provided by the Italian National Institute of Statistics (Istat), available at: http://dati-censimentipermanenti.istat.it/Index.aspx?DataSetCode=DCSS_ABITAZIONI, accessed 20/11/2024.

[8] Italy is divided into six climate zones, ranging from the warmest one (A) to the coldest one (F). Lombardy and Piedmont contain territories only in the two coldest zones, E and F.

and annual consumption of all types of energy (e.g., electricity, natural gas, GPL, coal).[9] Other technical details are provided, which we do not employ in our analysis.

For our work, the most relevant variables pertain to the recommendations provided by the domestic energy appraiser who gives advice on which retrofits are necessary to improve the energy efficiency of the property and who provides the energy class that could be reached should the recommended retrofits be implemented. Recommendations are grouped into six classes: 1. Opaque building envelope, 2. Transparent building envelope, 3. Climate control system (winter), 4. Climate control system (summer), 5. Other appliances, and 6. Renewable sources. For our analysis, we discard the last two for which we do not have enough information to perform the simulation. Specifically, class 6 (renewable resources) is of difficult simulation since the data do not provide the size of the solar panels to be installed. We consider this a reasonable approximation, since the two classes together represent only about 5% and 9% of the whole set of recommendations for residential units in Lombardy and Piedmont, respectively.

Alongside recommendations, another relevant variable of our analysis is the energy class. The energy performance of a building depends on how well it performs compared to a reference one, where the reference building has the same geometric characteristics, exposure and location of the building to be certified but with energy performance parameters equivalent to class A1. The energy class of each housing unit is based on the ratio between its own global non-renewable energy performance index and the reference standard one, according to the scheme depicted in Table 1.

Class A4			ratio	≤	0.40
Class A3	0.40	<	ratio	≤	0.60
Class A2	0.60	<	ratio	≤	0.80
Class A1	0.80	<	ratio	≤	1.00
Class B	1.00	<	ratio	≤	1.20
Class C	1.20	<	ratio	≤	1.50
Class D	1.50	<	ratio	≤	2.00
Class E	2.00	<	ratio	≤	2.60
Class F	2.60	<	ratio	≤	3.50
Class G			ratio	>	3.50

Note: ratio = 'EPgl, non renewable'/'EPgl, non renewable, reference, standard'

Source: Decree 26/06/2015, Ministry of Economic Development

[9] Energy performance indexes are technical parameters expressing the total consumption of primary energy for climate control, water heating, and lighting by unit of usable surface. They are expressed in kWh/sqm per year.

Table 1 Buildings' energy performance

To carry out our analysis we need the energy class attained once the renovation work is carried out: this piece of information is included in the EPC alongside each recommendation. For instance, the energy appraiser who recommends an opaque building envelope must also state by how many classes the energy efficiency of the dwelling would increase.

Before starting our analysis, we proceed with data cleaning. First, we drop historic buildings, which are excluded from the Directive. Buildings of historical (or artistic) interest are those subject to a monumental restriction by decree of the Minister of Cultural and Environmental Heritage, in accordance with the procedural requirements of Legislative Decree 490/1999. Since we cannot identify historical buildings in our dataset according to this definition, we follow Istat (2014) and define as historic the buildings constructed before 1919, despite being aware that this criterion may not fully capture the complexities of the legal definition.[10] Second, we exclude EPCs without any recommendation in the first four categories, as well as those with missing values of energy performance index, energy class, surface or construction year. Third, to reduce the effects of possible outliers, we winsorise some variables (gas and electricity consumption, CO2 emissions, usable heated surface and the non-renewable energy performance index) at the bottom (0.5%) and at the top (99.5%) of their distribution. The final number of observations is 901,843 in Lombardy and 367,176 in Piedmont: descriptive statistics of the variables employed in the analysis are depicted in Table 2 and Table 3 for Lombardy and Piedmont, respectively.

Variable	**Mean**	**Median**	**Min**	**Max**	**Std. Dev.**	**Relative Freq. (%)**
CO2 emissions (kg/m2/year)	45.82	40.26	6.38	151.70	25.41	
Electricity consumption (kWh/year)	555.88	65.11	0.00	10683.71	1280.81	
Gas consumption (m3/year)	1568.79	1198.08	0.00	8956.85	1434.74	
Useful heated surface (m2)	82.62	73.00	19.44	340.00	45.80	
Total		2	1	4		100
Class 1: 0-49.99						20.92
Class 2: 50-74.99						31.54
Class 3: 75-99.99						24.19
Class 4: >99.99						23.35

[10] The choice is justified by the fact that 1919 roughly corresponds to the year of introduction of the reinforced concrete technology and the consequent end of traditional construction techniques (Istat, 2014, p. 204).

Construction year		3	1	6		100
Class 1: 1919 - 1946						9.31
Class 2: 1946 - 1960						16.41
Class 3: 1961 - 1976						32.38
Class 4: 1977 - 1992						16.74
Class 5: 1993 - 2006						16.15
Class 6: After 2006						9.01
Dwelling type		0	0	1		100
Type 1: Flat						94.00
Type 2: Detached/semi-detached house						6.00
Climate zone		1	1	2		100
Zone 1: E						96.21
Zone 2: F						3.79
Energy performance		6	1	7		100
Class 1: A						3.82
Class 2: B						2.59
Class 3: C						4.64
Class 4: D						10.96
Class 5: E						16.99
Class 6: F						25.27
Class 7: G						35.73

Source: Authors' elaborations on EPCs data

Table 2 Descriptive statistics: Lombardy

Variable	Mean	Median	Min	Max	Std. Dev.	Relative Freq. (%)
CO_2 emissions (kg/m2/year)	43.01	36.60	1.60	203.90	27.98	
Electricity consumption (kWh/year)	889.03	295.00	0.00	13697.00	1532.33	
Gas consumption (m3/year)	1592.11	1102.64	48.00	19791.00	2003.76	
Useful heated surface (m2)	85.62	72.26	20.00	589.76	59.42	100
Class 1: 0-49.99						19.45
Class 2: 50-74.99						34.13
Class 3: 75-99.99						23.37
Calss 4: >99.99						23.05
Construction year		3	1	6		100
Class 1: 1919 - 1946						14.55
Class 2: 1946 - 1960						22.91
Class 3: 1961 - 1976						36.01
Class 4: 1977 - 1992						12.49
Class 5: 1993 - 2006						8.09
Class 6: After 2006						5.94
Dwelling type		0	0	1		100
Type 1: Flat						89.5
Type 2: Detached/semi-detached house						10.5
Climate zone		1	1	2		100
Zone 1: E						89.39

Zone 2: F				10.61
Energy performance	6	1	7	100
Class 1: A				4.82
Class 2: B				2.17
Class 3: C				5.07
Class 4: D				13.67
Class 5: E				23.56
Class 6: F				27.56
Class 7: G				23.14

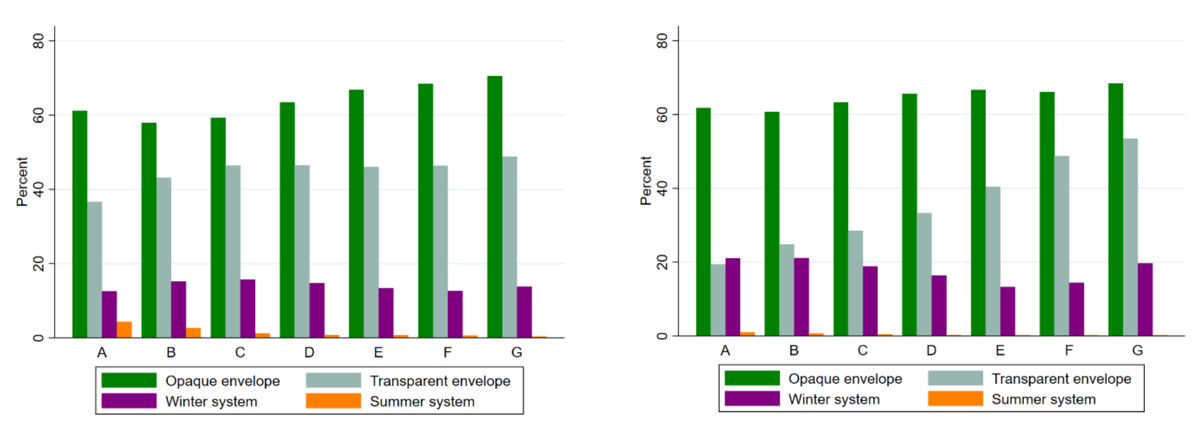
Source: Authors' elaborations on EPCs data

Table 3 Descriptive statistics: Piedmont

As for how the two regions compare to the others and to Italy as a whole, ENEA's data portal SIAPE does not provide the distribution of residential buildings by energy class and by region, which is available only for Italy as a whole. By comparing the residential dwellings' distribution by energy class of Lombardy and Piedmont with that of Italy we observe a very similar distribution for classes from B to F. More marked differences are detected in class A (11.1% in Italy, vs. 3.8% in Lombardy and 4.8% in Piedmont in our data) and in class G (30.9% in Italy, vs. 35.7% in Lombardy and 23.1% in Piedmont in our data); however, the percentage of dwellings in class G in the two regions together is 32%, which is very close to that of Italy (30.9%).

The distribution of the four considered recommendations is depicted in Figure 1. There is evidence that higher energy classes are associated with newer dwellings (Figure 2); however, the two regions display a low average level of energy efficiency.

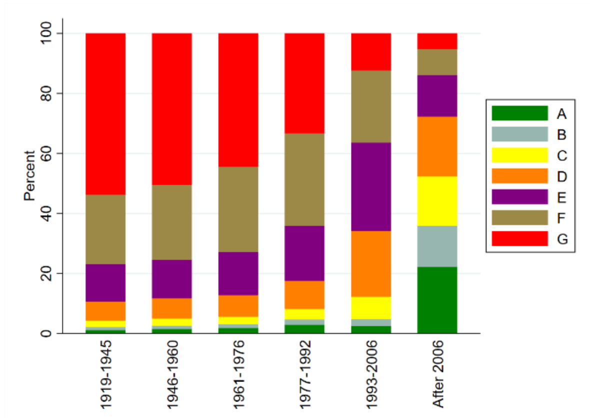
(a) Lombardy (b) Piedmont

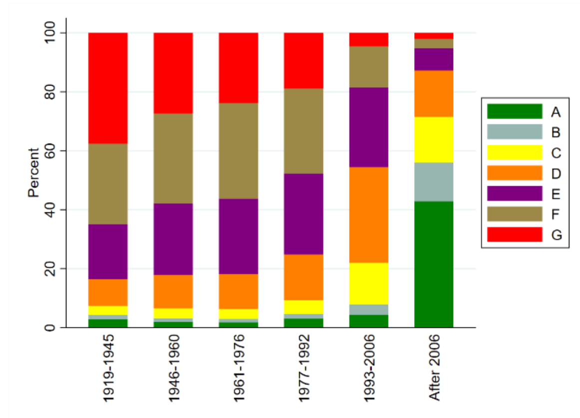


Source: Authors' elaborations on EPC data.

Figure 1 Recommendations by energy class (%)

(a) Lombardy	(b) Piedmont





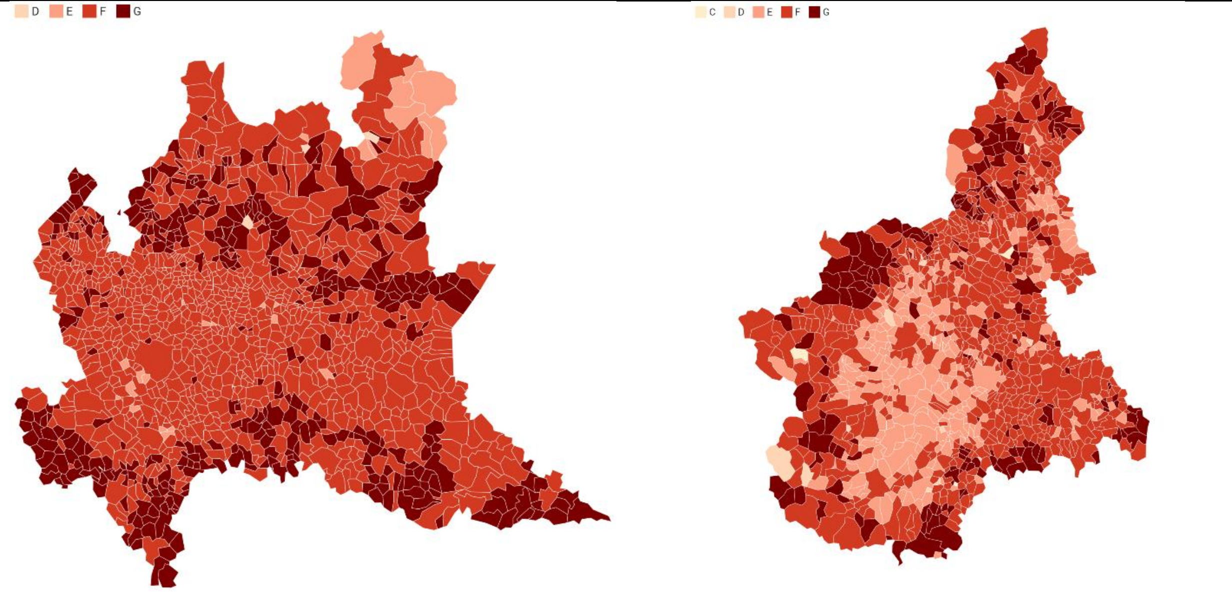
Source: Authors' elaborations on EPC data.

Figure 2 Energy performance class by year of construction (%)

Figure 3 depicts average energy performance classes by municipality. The values are based on the weighted average of the ratio between the non-renewable energy performance index and the reference standard non-renewable energy performance index, where the weights are the usable heated surface of each housing unit – the so-called K-index (Fabbri and Gaspari, 2021). Then, based on the values obtained by municipality, we employ the reference scale of Table 1 to assign the class by area, from G to A.[11] In Lombardy (Figure 3a), the great majority of municipalities is characterised by an average EPC belonging to class F (77.1%), followed by class G (19.4%). Similarly, in Piedmont (Figure 3b), the most represented class is F (58.1%), followed by class G (26.0%); the higher proportion of low-class buildings than in Lombardy reflects the older dwelling stock in the region, as reported in Tables 2 and 3.

(a) Lombardy	**(b) Piedmont**

[11] The most efficient energy classes (A1, A2, A3 and A4) were combined into a single 'A' class.

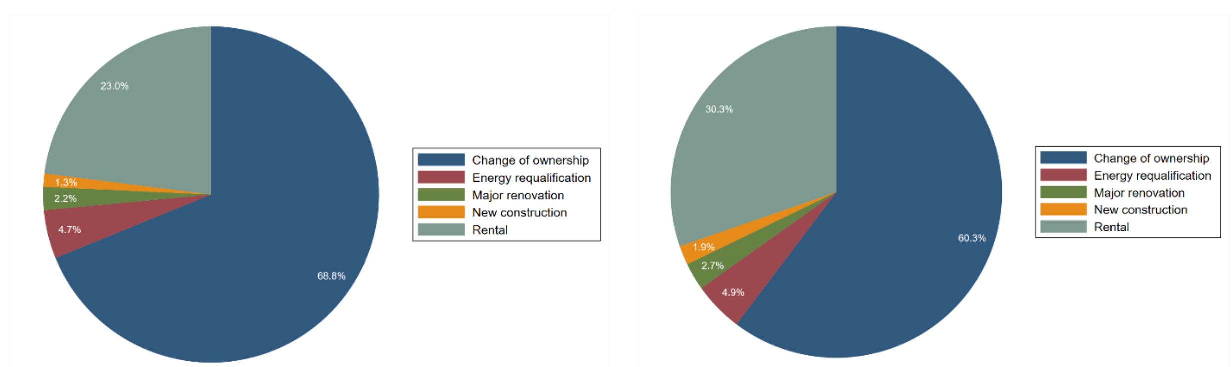


Source: Authors' elaborations on EPC data.

Figure 3 Average energy performance class by municipality

In both regions, the main reason for filling in an EPC is for change of ownership (68.8% in Lombardy and 60.3% in Piedmont), followed by renting out the dwelling (23.0% in Lombardy and 30.3% in Piedmont), as shown in Figure 4.

(a) Lombardy (b) Piedmont



Source: Authors' elaborations on EPC data.

Figure 4 Reasons for filling in an EPC (%)

4. The simulation exercise

In this section, we present the methodology followed to simulate the costs and the benefits of implementing the recast EPBD-2023 and the associated results. The Directive set that dwellings in classes G and F must switch to at least class E by 2030 and that those in class E must switch to at least class D by 2033. To avoid double counting, we look at the costs and benefits of moving to class E, instead of 'at least to' class E. As we will show later in the paper, upgrading the least energy efficient buildings is the best strategy to reach also the targets of the latest version of the EPBD, the EBPD-2024, as the gains in term of energy savings and emissions reductions are larger when retrofitting the most inefficient buildings and decrease as we move up along the EPC efficiency levels. Moreover, we are aware that not all homeowners are willing to implement the recommended retrofits (see, for instance, Curtis et al., 2024), however herein we assume that all households undertake the recommended energy renovations since we want to estimate the overall cost implied by the Directive.

To differentiate the estimate of the costs and benefits by dwelling characteristics, we build clusters of dwellings based on the following features: usable heated surface split into quartiles, construction year grouped into six classes, whether the dwelling is a flat or a detached/semi-detached house (binary variable), climate zones (in both Lombardy and Piedmont we have only two climate zones, E and F, which are the coldest ones), and energy performance grouped into seven classes (from G to A). For each region, we obtain a total number of clusters equal to 672, whose distribution is reported in Table 4.

Region	**No. of clusters**	**Cluster size**				
		Min.	**p25**	**Median**	**p75**	**Max**
Lombardy	672	0	14	82	655	39,973
Piedmont	672	0	20	85.5	366	15,501

Source: Authors' elaborations on EPCs data

Table 4 Distribution of clusters

4.1 Costs

To compute the cost of switching from classes G and F to E and then to D, we proceed by steps. First, we look at the four selected recommendations provided by the energy appraiser to each housing unit, and we impute the cost of the recommendations to each property belonging to the two least efficient classes. To do so, we refer to the price listings of the first semester 2024 (the latest available) used by engineers, architects and surveyors to provide retrofit works estimates to homeowners (DEI, 2024).[12] These unitary prices are intermediate ones, that is they reflect the cost of material, labour and installation, but exclude VAT, which we add by applying the standard 10% rate to get final prices (Table 5).

For recommendations of groups 1 and 2, we need the distinction between opaque and transparent envelope surfaces, which are not provided in the dataset (we only have the overall envelope surface). To obtain them, we look at the building regulations of the city of Milan and Turin – the capital cities of the two regions – that provide the minimum transparent surface that a property must have as a percentage of the dwelling's heated surface (12.5% in both).[13] We apply this percentage to the dwelling's heated surface to get the transparent one, which we subtract from the overall dwelling's envelope surface to get the opaque surface of each property. Then, we apply the unitary cost of Table 5 to the two estimated surfaces. For the winter climate control system, we assume that the heater has an average power of 24kWth, while for the summer climate control system we assume that the heat pump has an average power of 5kWth.[14]

Retrofit type	**Description**	**Intermediate price (a)**	**Final price (b)**
Opaque building envelope	Perimeter wall insulation	135.1 €/sqm	148.6 €/sqm
Transparent building envelope	Replacement of windows, including frames	834.2 €/sqm	917.6 €/sqm
Climate control system - winter	Replacement/installation of the gas heater	7,791.5 €/kWth	8,570.6 €/kWth

[12] Each recommendation within each category can be implemented with different materials with different specificities: we take the average price of all the options for each of the four categories of renovation works.

[13] For Milan, see: https://www.comune.milano.it/aree-tematiche/edilizia/sportello-unico-edilizia/regolamento-edilizio, accessed 20/11/2024. For Turin, see: http://www.comune.torino.it/regolamenti/delibere/2018/2018_02466/201802466_1.pdf, accessed 20/11/2024.

[14] The power values of the most installed summer/winter climate control systems were provided by a domestic energy appraiser we contacted to get some technical insights on EPCs.

Climate control system - summer	Replacement/installation of the cooling system pump	4,240.9 €/kWth	4,665.0 €/kWth

Note 1: Intermediate prices reflect only the cost of material, labour and installation, while final ones also include VAT.
Note 2: In columns (a) and (b), sqm stands for square metre, kWth stands for kilowatt-thermal.
Source: Authors' elaborations on DEI and Istat data

Table 5 Retrofit types and unitary costs (€)

Finally, since for each property the appraiser may provide more than one recommendation – each of which would allow the property to upgrade its energy performance class – to avoid double counting we take the recommendation that allows the housing unit to get to the desired class with the lowest associated cost. Table 6 provides the estimated costs for residential unit in Lombardy and Piedmont to switch to class E from classes G and F and to at least class D from class E: they are computed as the weighted mean of the median minimum costs by cluster, where the weights are the cluster numerosity.[15]

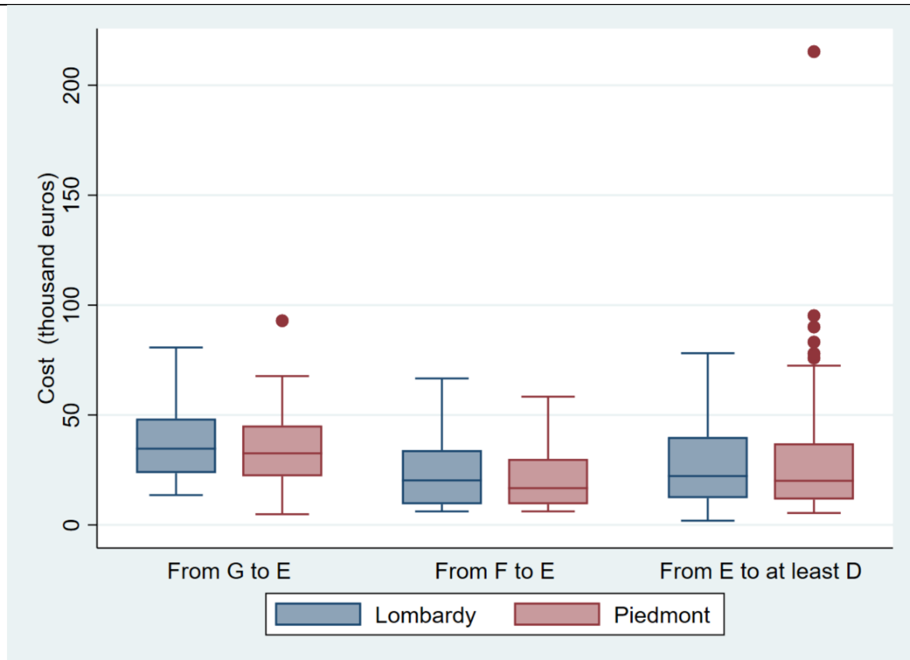
	From class G to class E	From class F to class E	From class E to at least class D
Lombardy	30,682	14,632	15,507
Piedmont	27,460	13,421	15,369

Source: Authors' elaborations on EPCs data

Table 6 Estimated cost per dwelling (€)

Figure 5 shows the distribution of the costs, depicting their quartiles by class switch and region, with whiskers extending to the most extreme data points not considered outliers.

[15] We take the median value since the distributions of the costs are skewed to the right.



Source: Authors' elaborations on EPC data.

Figure 5 Box plot of retrofit costs by class switch and region

Since our objective is to estimate the overall cost of switching from classes G and F to E, and then from class E to at least class D, for the whole housing stock of Lombardy and Piedmont, we must impute a cost to the housing units not included in the EPC datasets (i.e., those for which an EPC is not available).

The easiest approach would be to assume that the samples are random draws from the overall dwelling stock of the two regions and then to assign the estimated cost to all the existent dwellings. However, we have a bias due to the presence of new buildings in the samples: they are likely to represent the whole of newly built dwellings in the two regions, as for them it is compulsory to have an EPC since 2012, and their energy efficiency is obviously much higher on average. To avoid the bias, we refer to the number of existing dwellings before the starting date of our dataset, which is 2015. Cresme et al. (2024) provide the number of non-historic occupied dwellings by year of construction: we use this information to exclude housing units built after 2011 and obtain a total number of dwellings subject to the EPBD equal to 3,475,082 in Lombardy and 1,463,191 in Piedmont.[16] Now, after excluding the dwellings used only occasionally (as second homes) from the EPC data since they are not subject to the EPBD, we compute the relative frequencies of housing units in classes G and F and apply them to the above values. In Lombardy, the percentages are 32.3% for class G and 25.1% for class F, while in Piedmont the percentages are 22.7% and 27.6% for class G and F, respectively. Therefore, in Lombardy we estimate that 1,123,842 dwellings are in class G and 873,288 in class F, while in Piedmont 332,583 are in class G and 403,841 in class F.

Now that we have an overall number of buildings in classes G and F for the two regions, we assign them the estimated cost to switch from classes G and F to class E, as reported in Table 6. Hence, we obtain the potential overall cost to bring Lombardy's and Piedmont's housing stock to class E: €47.3 billion for Lombardy and €14.6 billion for Piedmont (first column of Table 7).

The next step set by the EPBD-2023 is that all buildings need to reach at least class D. As the previously calculated costs allowed the whole housing stock to reach class E, we assume that there are no more F- and G-class buildings left in the sample: the proportion of buildings in class E is, thus, equal to the proportion of E-class buildings in the sample plus the share of F-class and G-class buildings (since these have supposedly already performed the switch to class E). In the EPC data, E-class buildings represent 17.5% of the sample in Lombardy and 23.7% in Piedmont. Therefore, we can assume that the updated proportion of E-class buildings is equal to 32.3+25.1+17.5=74.9% in Lombardy and 22.7+27.6+23.7=74.0% in Piedmont, so that we estimate the total number of E-class housing units to be 2,602,836 in Lombardy and 1,082,761 in Piedmont. Then, we assign the unitary cost of switching from class E to at least class D of Table 6 to the total updated number of E-class dwellings in the two regions, which results in the estimated potential overall cost displayed in the second column of Table 7: €47.3 billion in Lombardy and €14.6 billion in Piedmont, for a total of €61.8 billion.

Overall, we estimate the final cost of bringing the whole building stock of the analysed regions first to class E and then to at least class D to be €87.6 billion for Lombardy and €31.2 billion for Piedmont, for a total of €118.9 billion (Table 7, third column), which represents 20.2% of the two regions' GDP and 5.6% of Italy's GDP. The size of this figure makes it clear that the financial

[16] We refer to figures in Table 5.2 in Cresme et al. (2024), which are their elaborations on Istat data.

burden of the recast EPBD cannot be entirely borne by the private sector by itself but requires government intervention: some suggestions on how to approach the issue are outlined in Section 5.

	From classes G and F to class E	From class E to at least class D	Total
Lombardy	47.3	40.4	87.6
Piedmont	14.6	16.7	31.2
Total	61.8	57.0	118.9

Source: Authors' elaborations on EPCs data

Table 7 Total estimated cost (billions of €)

Finally, we provide an estimate of the cost for the whole of Italy under the assumption that the average unitary costs in the remaining regions are equal to the weighted averages of those of Lombardy and Piedmont of Table 6. We proceed by steps: first, we retrieve the percentages of total dwellings by energy class and region from the SIAPE, second we take the total number of non-historic residential dwellings from Cresme et al. (2024) (as in our simulations for Lombardy and Piedmont) and compute the number of dwellings in each energy class by applying the percentages of the first step, and finally we multiply the number of dwellings by the estimated individual average cost of Lombardy and Piedmont of Table 6. We obtain an overall cost of €440 billion, which is 20.7% of Italy's GDP.

4.2 Benefits

Herein, we proceed to the estimation of the public and private benefits (reduction in CO2 emissions and gains from lower electricity and gas expenditure) for the dwellings for which we have computed the retrofit costs implied by the EPBD-2023. To this end, we look at CO2 emissions (kg/year) and consumption of gas (m^3/year) and electricity (kWh/year) associated to the buildings in the dataset.[17]

Specifically, starting from the clustering method used to assess the cost of transitioning from energy-efficiency classes G and F to E, and then to D, we compare median emissions, gas consumption and electricity consumption among clusters of dwellings characterised by similar surface, construction year, dwelling type and climate zone, but with a different energy performance class.

Thus, we consider the difference between the median values assigned to groups of similar dwellings at distinct levels of energy efficiency (G compared to E, F compared to E, and E compared to each higher class), determining the unitary benefits for the two regions and the three class switches (G to E, F to E, and E to at least D) as the weighted average of the calculated differences, in which the number of recommendations in each cluster for each considered class switch is taken as weight. The resulting unitary benefits are presented in Table 8. In Lombardy, class switches occasionally show negative values of electricity usage, which correspond to higher consumption, attributable to the shift from traditional gas-based heating systems to electric heat pumps. Concerning the benefits in terms of CO2 reduction, the resulting values represent the decrease in CO2-equivalent emissions in kilograms per year for an average dwelling. In the case of switching from class G to class E, we find CO2-equivalent savings of around 2.4 tons in Lombardy and of around 2.2 tons in Piedmont per dwelling per year, while a switch from F to E is associated with a yearly reduction in emissions of around 680 kg in Lombardy and of around 780 kg in Piedmont. Switching from class E to at least class D is instead associated to a dwelling-level reduction in emissions of 710 kg and 630 kg in Lombardy and Piedmont, respectively.

	From class G to class E	**From class F to class E**	**From class E to at least class D**
		CO2 emissions (kg/year)	
Lombardy	2,415	675	713
Piedmont	2,239	778	630

[17] Consumption is defined as the theoretical level of gas and electricity necessary to keep a temperature of 18° Celsius in the dwelling and is not actual consumption. We are aware that this is a limitation of our analysis, and that further research is needed to link theoretical consumption with actual one.

	Electricity consumption (kWh/year)		
Lombardy	-116	-79	-161
Piedmont	308	127	19
	Gas consumption (m3/year)		
Lombardy	1,185	363	404
Piedmont	1,057	368	319
	Monetary savings (€/year)		
Lombardy	1,124	334	353
Piedmont	1,109	391	315

Source: Authors' elaborations on EPCs data

Table 8 Estimated annual benefits per dwelling

As regards gas and electricity consumption, we transform the obtained values, measured in cubic metres and kWh respectively, into monetary expenditure, by employing the gas and electricity prices provided by Enerdata (Table 8).[18] Given the energy price surge of 2022 and 2023, we take the average value in real terms of the period 2010-2021 for both energy items: the values are 0.947 euro/m^3 and 0.268 euro/kWh at 2023 prices for gas and electricity, respectively. Monetary savings are calculated by multiplying the change in gas and electricity consumption by their average costs. Therefore, the resulting value is the total saving in euro per year at the regional level, taking gas and electricity together. An average dwelling is estimated to save just over €1100 per year when switching from class G to class E in both regions, while the figure drops to values in the range €334-€391 for an F-to-E switch and to values in the range €315-€353 in the case of transitioning from class E to at least class D.

Similarly to what done above for the estimation of the costs, unitary benefits are next scaled up by the estimated number of dwellings at the regional level for each starting energy performance class, with a view to allocating the gains from the retrofits to the dwellings not covered in the dataset (i.e., those without an EPC). The total estimated benefits are presented in Table 9. We estimate the total annual benefits of bringing the whole building stock of the analysed regions first to class E and then to at least class D to be about €2.5 billion for Lombardy and €0.9 billion for Piedmont,

[18] Electricity and gas prices are provided by Enerdata (https://www.enerdata.net/, accessed 20/11/2024) that gathers energy prices and consumption volumes from regional and national official data sources.

for a total of over €3.3 billion. The associated annual reduction in CO2-equivalent emissions is of 6.9 million tons in the two regions (5.2 million tons in Lombardy and 1.7 million tons in Piedmont).

	From classes G and F to class E	**From class E to at least class D**	**Total**
	CO2 emissions (kton/year)		
Lombardy	3,303	1,856	5,159
Piedmont	1,059	683	1,742
Total	4,362	2,539	6,901
	Electricity consumption (GWh/year)		
Lombardy	-200	-420	-620
Piedmont	154	20	174
Total	-46	-400	-446
	Gas consumption (Millions of m3/year)		
Lombardy	1,649	1,053	2,702
Piedmont	500	345	845
Total	2,149	1,398	3,547
	Monetary savings (Millions of €/year)		
Lombardy	1,555	918	2,473
Piedmont	526	342	868
Total	2,081	1,260	3,341

Source: Authors' elaborations on EPCs data

Table 9 Total estimated annual benefits

To get an idea of how expected benefits may change according to different price scenarios, we refer to NGFS (Network for Greening the Financial System) prices in two of the seven scenarios, that is Net Zero and Fragmented World, which are the two extreme ones.[19] The Net Zero scenario limits global warming to 1.5° Celsius through stringent climate policies and innovation, with the aim of reaching global net zero CO2 emissions around 2050, while the Fragmented World one assumes delayed and divergent climate policy ambition globally, leading to high physical and transition risk. Table 10 displays all NGFS prices: for the purpose of our analysis, we take 2025-

[19] NGFS prices are available, after registration, at the link: https://www.ngfs.net/ngfs-scenarios-portal/, accessed 20/11/2024. For technical details, see NGFS (2023).

2035 average values for electricity and gas of our two selected scenarios. It is noteworthy that these prices are not specific to Italy but refer to Europe as a whole.

	2020	2025	2030	2035	2040	2045	2050	2025-2035 average
Electricity (euro2023/Kwh)								
Low demand	0.2251	0.1643	0.1807	0.1938	0.1805	0.1700	0.1695	0.1796
Net Zero 2050	0.2251	0.2312	0.2324	0.2139	0.1841	0.1645	0.1638	0.2258
Below 2°C	0.2251	0.2140	0.2005	0.1899	0.1812	0.1723	0.1711	0.2014
Nationally Determined Contributions (NDCs)	0.2251	0.2255	0.2234	0.2082	0.1853	0.1696	0.1685	0.2191
Current Policies	0.2251	0.2158	0.2028	0.1921	0.1817	0.1718	0.1731	0.2036
Delayed Transition	0.2251	0.2158	0.2028	0.2001	0.1996	0.1822	0.1679	0.2062
Fragmented World	0.2251	0.2158	0.2028	0.1964	0.1884	0.1785	0.1775	0.2050
Gas (euro2023/m3)								
Low demand	0.7002	0.6496	0.9504	1.2644	1.3926	1.3781	1.3579	0.9548
Net Zero 2050	0.7002	0.9872	1.4120	1.8152	1.9341	1.8472	1.8375	1.4048
Below 2°C	0.7002	0.7996	0.8829	0.9104	0.9400	1.0077	1.1085	0.8643
Nationally Determined Contributions (NDCs)	0.7002	0.9201	1.1310	1.2000	1.1869	1.1949	1.2381	1.0837
Current Policies	0.7002	0.7915	0.8465	0.8449	0.8399	0.8601	0.9050	0.8276
Delayed transition	0.7002	0.7915	0.8465	1.0915	1.4820	1.6617	1.6759	0.9098
Fragmented World	0.7002	0.7915	0.8465	0.8740	0.9194	0.9965	1.0871	0.8374

Source: NGFS data.

Table 10 Prices for electricity (€2023/kWh) and natural gas (€2023/m3) for the Italian residential sector under different NGFS scenarios

Table 11 shows the estimated annual monetary savings under the two scenarios and the baseline one for clarity of reading: annual savings under the Net Zero scenario are €4,882 million, 46.1% higher than those of the baseline scenario, while savings under the Fragmented World one are €2,879million, that is 13.8% lower than the baseline. The difference is mainly imputable to the different gas price trend, as shown in Table 10.

	Lombardy	Piedmont	Total
Baseline	2,473	868	3,341
Fragmented World	2,135	744	2,879

Net Zero 2050	3,655	1,227	4,882

Source: Authors' elaborations on EPC data and NGFS data.

Table 11 Monetary savings under different NGFS scenarios and our baseline scenario (millions of €/year)

Finally, we are aware that there may be a gap between projected and realised energy savings from energy efficiency upgrades (Allcott and Greenstone, 2017; Fowlie et al., 2018; Christensen et al., 2023). While our study projects future energy savings based on EPC data, it does not explicitly account for potential deviations between these estimates and the actual savings achievable through renovation work. Actual savings could be lower due to behavioural effects, such as achieving a higher level of comfort (for example higher levels of heating) instead of a reduction in energy consumption. Such gap may lead to an overstatement of the energy savings in our cost-benefit analysis; however, it is difficult to incorporate this gap in our simulations because the above-mentioned studies refer to very specific cases of the US market. Future studies could benefit from specific analysis of the Italian case and from incorporating the estimates into new simulations to enrich the debate.

4.3 A comparison between EPBD-2023 and EPBD-2024

The EPBD-2024 sets that each country should reduce the residential buildings' energy consumption by 16% by 2030 and by 20-22% by 2035, while the EPBD-2023 works with energy class switches. Our choice of simulating the EPBD-2023 is dictated by the structure of our microdata, which allow us to associate unitary costs to retrofits aimed at upgrading the energy class. However, by employing SIAPE aggregate data we are able to quantify the reduction of aggregate energy consumption implied by the EPBD-2023 and compare it with the EPBD-2024 target.

To perform this additional simulation exercise, we build clusters based on two dimensions – climate zone and heated usable surface of the dwelling – so that we can compare energy consumption of each cluster by energy class. Then, we compute the reduction in energy consumption of clusters switching, at a first stage, from classes G and F to class E and, at a second stage, from class E to at least class D. The first stage implies a reduction in energy consumption of 18.5%, close to the 16% of the 2030 requirement. Both stages together imply an overall fall in consumption of 27.9%, which overshoots the 20-22% EPBD-2024 target of 2035.

A strategy to limit this reduction would be to exclude the dwellings that have already switched from G/F to E from the second stage and include only those that were already in class E. Specifically, this strategy would require the worst-performing buildings (those in class G) to upgrade by two energy classes and those in classes F and E to upgrade by one energy class. This strategy would imply an energy consumption reduction of 21.5%, in line with the EPBD-2024. The estimated overall cost for Italy, obtained through the methodology described in Section 4.1, would be €280 billion, as opposed to €440 billion.

5. Cost-benefit analysis and policy implications

In this section we compare the costs and the benefits, both private and social, we derived in the previous section and perform a simple cost-benefit analysis for a class switch to get an estimate of the breakeven year, that is how many years of future benefits are needed to compensate for the intervention cost to be paid upfront.[20] Figure 6 depicts the cost-benefit analysis for the upgrade from class G to class E in Lombardy.[21] The horizontal line is the cost of €30,682 from Table 6. The upward sloping lines show three types of cumulative benefits. First, we compute private cumulative benefits, derived as the discounted sum of the overall yearly monetary savings from Table 8. Second, we compute the social benefit as the discounted sum of the monetary value of the yearly reduction in CO_2 emissions, assuming a Social Cost of Carbon (SCC) of 805€/tonCO_2 in 2024, as published by the German Environmental Agency and consistent with a social discount factor of 2% in 2021 and linearly decreasing to 1% in 2250.[22] Finally, the total benefit is derived

[20] A similar approach is employed by Alpino et al. (2023) to provide a baseline quantitative assessment of the green projects included in the Italian NRRP (National Recovery and Resilience Plan).

[21] For the sake of exposition, we show the analysis just for one of the interventions presented in the previous section. The analyses for the other class switches are similar.

[22] The German Environment Agency (UBA) publishes two recommended social costs of carbon based on a methodological convention (https://www.umweltbundesamt.de/daten/umwelt-wirtschaft/gesellschaftliche-kosten-von-umweltbelastungen#klimakosten-von-treibhausgas-emissionen, accessed 20/11/2024), available, in German, at the following link: https://www.umweltbundesamt.de/publikationen/methodenkonvention-umweltkosten, accessed 20/11/2024.

as the sum of the two benefits. The intersection of any of the upward sloping curve with the horizontal line defines the break-even year: Figure 6 shows that the break-even year taking into account the total benefits is around 11 years. From the cost-benefit analysis we learn that, for the interventions analysed here, social benefits dominate private ones from savings in energy consumption. This result seems to justify the use of government subsidies.[23]

Since the government is called upon by European regulations to intervene to increase dwellings' energy efficiency, it is advisable to outline desirable criteria to design the interventions by accounting for various elements, among which the choice of the instrument, the choice of the beneficiaries and the size of the incentive.[24]

Firstly, the main instrument that most European governments, including Italy since the late 1990s, have used to stimulate investment in buildings' energy efficiency is the tax credit, which allows households to write off a share of the investment from their tax liabilities. Amenta and Stagnaro (2021) compare the different incentives that are in place across European countries and show that the Italian framework is far more generous than that of any other country, even before the introduction of the aforementioned 'Superbonus'. Nevertheless, as the EPC data and our results show, the Italian residential building stock still needs a significant amount of renovation, raising the question on whether the measures that have been in place were ill-suited to stimulate investments in building renovations and on how they can be improved. Another way to incentivise energy efficiency interventions is to give access to 'green mortgages', under which a bank or mortgage lender offers a house buyer preferential terms (for instance, an interest rate discount) if they can demonstrate that the property for which they are borrowing meets certain environmental standards. Moreover, governments can incentivise access to this type of mortgage through the granting of tax rebates or public guarantees. In Italy, there is evidence that the market for this type of mortgages is growing and has reached 6% of overall mortgages (Abate et al., 2024). Other instruments whose relative market weight is increasing are 'green bonds' (Doronzo et al., 2021; European Banking Authority, 2023), which enable capital-raising and investment for new and

---

[23] Camboni et al. (2024) show that for the province of Treviso in the north-east of Italy, without any subsidy only 15% of the recommended energy efficiency enhancing investments are likely to be implemented, while the adoption of a subsidy covering 50% of the costs brings the likelihood to 30%.

[24] For a discussion, see De Blasio et al. (2024).

existing projects to finance environmentally sound and sustainable projects that foster a net-zero emissions economy and protect the environment. Nevertheless, this instrument should not apply for residential real estate, since such financing instruments are not typically available for households.

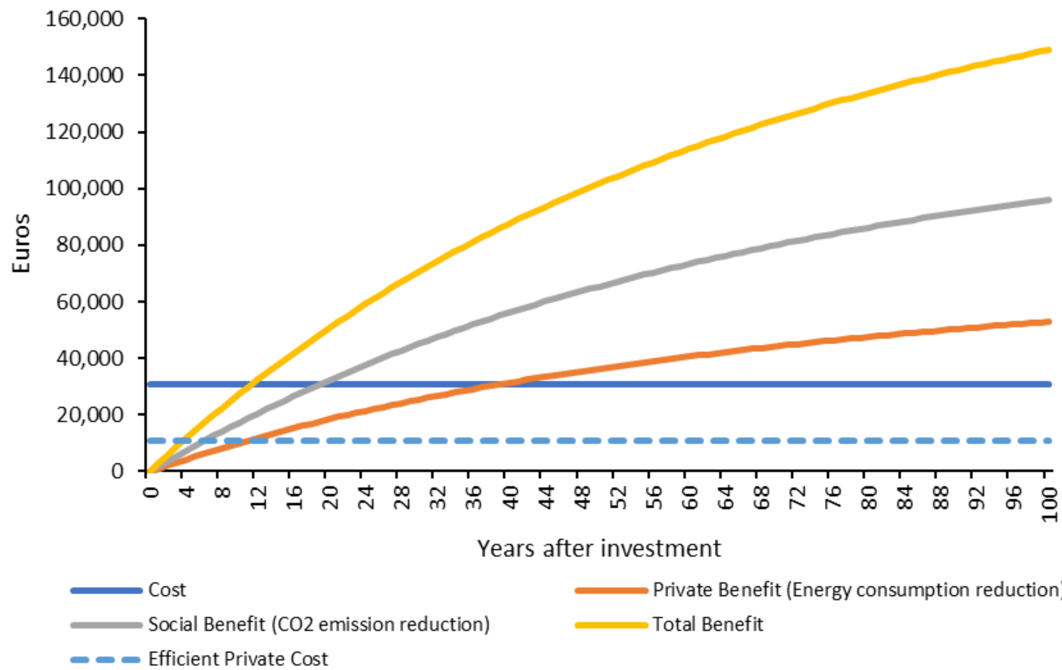
Secondly, as a matter of principle it is advisable that the resources be directed towards the least wealthy households – who also face liquidity problems – since there is evidence that green technologies tend to be adopted disproportionately by high-income households (Davis, 2023). The 'Superbonus' allowed two alternative ways to get access to the tax credit: one was selling the tax credit on a secondary market ('cessione del credito'), while the second one was getting a discount – equal at most to the amount of the tax credit – directly when paying for the renovation works ('sconto in fattura'): in the latter case, the construction company responsible for the renovation work would receive the tax credit and either use it against its tax liabilities, or else sell it on the secondary market. These instruments turned out to be effective ways to allow the poorest households to get access to the subsidies. UPB (2023) shows that the 'Superbonus' was less regressive than the previous measures. However, one could imagine a more progressive scheme for the tax credit, such as the one implemented by the French government, in which its rate decreases with household income in a range from 90% to 40%. As far as Italy is concerned, we suggest the use of the means testing criterion ('Indicatore della Situazione Economica Equivalente') used to give access to social welfare benefits and that considers both household income and wealth.

Thirdly, as far as the efficient aggregate size of the government subsidy is concerned, our cost-benefit analysis suggests that to make consumers internalise the social benefits of the upgrade, the government should decrease the cost of the intervention up to the point where the break-even year perceived by the consumer is comparable with the break-even year implied by the total benefits. The dashed horizontal line in Figure 6 shows that such value lies at around €11,000, implying a government subsidy of about 64%, which is a number remarkably close to the one in place in the current Italian framework. This framework, named 'Ecobonus', allows for a tax credit rate that ranges from 50% to 75%, depending on the type of retrofit and the type of residential unit considered, to be spread over ten fiscal years. However, financial feasibility of the current framework is a major concern. Let us assume that the upgrades we analysed in the previous section is conducted under the 'Ecobonus' framework. For the sake of simplicity, we assume a unique

65% tax credit rate: upgrading all the buildings in Italy would cost €286 billion (65% of the €440 billion as detailed in Section 4.1), corresponding to roughly an average of 0.72% of Italian GDP in tax credits every year until 2042.[25] Since the suspension of the EU fiscal rules ended in 2024 and given the current level of Italian public debt, this policy seems unfeasible and unsustainable.

Therefore, a question that arises is why these subsidies are not so widely exploited, if the Italian fiscal framework is characterised by a tax credit rate close to the level that seems to be efficient from our cost-benefit analysis. UPB (2023) showed that, by combining fiscal data with data on access to tax credits, fiscal measures to stimulate energy efficiency are typically regressive, with half of the amount of written-off tax liabilities pertaining to the richest 10% of the Italian population. Hence, the answer seems to lie in the fact that not all households are able to access the tax credit. On the one hand, households in the lowest tail of the income distribution are more likely to face liquidity constraints and to be unable to pay the whole amount of the investment in advance. On the other hand, even if they can, low-income households may not have the fiscal capacity to make the most out of the tax credit. Overall, our analysis suggests that the efficient tax credit rate to incentivise the private sector to undertake energy efficiency retrofits is about 65%, implying large fiscal deficits for the governments that will have to comply with the requirements of the EPBD-2024. Fiscal sustainability may require the government to fine-tune progressive features to the tax schemes to allow also low-income households to get access to the retrofits needed to upgrade the energy efficiency of their homes.

[25] To get the average annual spending, one should divide the total of €286 billion by 19 years and get €15.05 billion, which is approximately 0.72% of GDP. Indeed, according to the current legal framework, tax credits are spread over ten fiscal years, so that if the last tax credit is approved in 2033, the last expense incurred by the government takes place in 2042, 19 years after 2024.



Source: Authors' elaborations.

Figure 6 Cost-benefit analysis for class switch from G/F to E in Lombardy

6. Conclusions

In this paper, we estimate the costs and benefits associated with the implementation of the Energy Performance of Buildings Directive in two Italian northern regions (Lombardy and Piedmont). The 2023 version of the directive (EPBD-2023) set that dwellings in energy classes G and F must switch to at least class E by 2030 and those in class E to at least class D by 2033. We can estimate the cost and benefit of achieving these requirements by exploiting novel microdata on energy performance certificates of all dwellings for which a certificate has been filled in by an energy appraiser. This methodology, in turn, allows us to suggest a reasonable strategy to achieve energy and emissions savings that are consistent with the final version of the directive, the EPBD-2024.

The datasets cover the period 2015-2022 for Lombardy and 2015-2023 for Piedmont and represent 21.1% and 17.0% of the overall residential building stock of the two regions, respectively. They contain a wealth of information on buildings' characteristics. We concentrate on the current energy class, which ranges from G (the least efficient) to A4 (the most efficient), and on the recommendations provided by the domestic energy appraiser who gives advice on which retrofits are necessary to improve the efficiency of the property and provides the energy class that could be reached should the recommended retrofits be implemented. We look at four recommendations that cover more than 90% of all the retrofits: opaque building envelope, transparent building envelope, winter climate control system, and summer climate control system.

To compute the monetary costs, we refer to the unitary costs of each recommendation provided by market price listings for building renovations and apply them to the dwellings in our data according to the recommendation associated with the smallest cost. To attribute a cost to the dwellings that are not in our database – those without an EPC – we take the total number of non-historic occupied dwellings of the two regions and assume that the energy class distribution of all the buildings is the same as the one we have in the EPC datasets. The estimated total cost of implementing the EPBD-2023 for the two regions amounts to €118.9 billion, which is 20.2% of the total of the two regions' GDP and 5.6% of Italy's GDP. The size of this figure makes it clear that the financial burden of the EPBD-2023 cannot be borne by the private sector alone but requires government intervention. These costs are higher than what would be required to satisfy the EPBD-2024, but not by much. Switching dwellings from G and F to E, and those initially in E to D could satisfy the requirement of the EPBD-2024 at minimal costs, as retrofitting the least efficient buildings entails the larger gains in terms of both energy efficiency and emission reductions.

In both cases the costs involved are very high, and therefore the directive is likely to pose an important challenge to the Italian economy in terms of private and/or public resources needed. Government subsidies, in the form of tax credits, may be needed to incentivise and accelerate the building renovation rate. The paper also provides estimates of the efficient level of subsidies that should be involved and their costs for the budget, and of possible ways of deploying these incentives in a way which is progressive, as the existence of financial constraints may make these policies excessively regressive.

The implementation of the EPBD-2023 should lead to an annual reduction of CO2-equivalent emissions of 6.9 million tons in the two regions (5.2 million tons in Lombardy and 1.7 million tons in Piedmont). Monetary private gains are computed by applying electricity and gas prices to savings expressed in kWh/year for electricity and in m^3/year for gas: they amount to €2.5 billion yearly for Lombardy and to €0.9 billion for Piedmont yearly, for an annual total of over €3.3

billion. We have also presented some robustness exercises assuming different scenarios for electricity and gas prices.

Finally, we perform a cost-benefit analysis by comparing the costs incurred to enhance dwellings' energy efficiency and the associated benefits, both private and social, for switching from class G to E in Lombardy: the cost-benefit analysis tells us that the social benefits dominate the private ones, which implies that the use of government subsidies is justified. However, the estimated subsidy rate (65%) is indicative of the fact that the social benefit associated with the reduction in emissions dominates the private one associated with the reduction in energy costs for homeowners, implying that a significant contribution of public funds would be necessary to achieve the targets of the directive. The feasibility, at the current state of technology, of such financial commitment by the public sector is debatable.

The decarbonization of the building sector remains a necessity to achieve the net zero emission target. This paper shows that the cost of achieving this goal can be significant and a debate should ensue on the way these costs can be reduced. Partly this will come from improvements in the efficiency and prices of the required materials, partly from energy savings coming from behavioural changes, and partly potentially from the dismissal of the use of some of the most inefficient dwellings while at the same time building new ones with current standards. One limitation of this paper is not to address these possibilities.

Bibliographic references

Abate, L., Lionetti, V., Michelangeli, V. (2024), 'Is the Italian green mortgage market ready to take off?', Bank of Italy Occasional Papers No. 868

Accetturo, A., Olivieri, E., Renzi, F. (2024), 'Incentives for dwelling renovations: evidence from a large fiscal programme', Bank of Italy Occasional Papers No. 860

Allcott, H., and Greenstone, M. (2017), 'Measuring the welfare effects of residential energy efficiency programs', NBER Working Paper No. 23386

Alpino, M., Citino, L., Zeni, F. (2023), 'Costs and benefits of the green transition envisaged in the Italian NRRP – An evaluation using the social cost of carbon', *Energy Policy*, Vol. 182

Amenta, C., and Stagnaro, C. (2021), 'Quanto è efficiente l'Ecobonus?', *Energia*, Vol. 4, pp. 62-69

Baldini, M., Brøgger, M., Jacobsen, H. K., Wittchen, K. B. (2020), 'Cost-effectiveness of energy efficiency improvements for a residential building stock in a Danish district heating area', *Energy Efficiency*, Vol. 13, pp. 1737-1761

Berry, S., Marker, T., Chevalier, T. (2008), 'Modelling the Relationship between Energy Efficiency Attributes and House Price: The Case of Detached Houses Sold in the Australian Capital Territory in 2005 and 2006', 2008 ACEEE Summer Study on Energy Efficiency in Buildings

Bettarelli, L., Furceri, D., Pizzuto, P., Shakoor, N. (2024), 'Climate change policies and income inequality', *Energy Policy*, Vol. 191

Billio, M., Casarin, R., Costola, M., Veggente, V. (2024), 'Learning from experts: Energy efficiency in residential buildings', *Energy Policy*, Vol. 136

Bisello, A., Antoniucci, V., Marella, G. (2020), 'Measuring the price premium of energy efficiency: A two-step analysis in the Italian housing market', *Energy & Buildings*, Vol. 208, pp. 1-13

Borgarello, M., Croci, L., Talamo, F., Brugnetti, E., D'Oria, F., Sabbatini, S. (2023), 'Direttiva "case green": opportunità o asticella troppo alta?', *Energia*, Vol. 2, pp. 62-67

Braggiotti, F., Chiarini, N., Dondi, G., Lavecchia, L., Lionetti, V., Marcucci, J., Russo, R. (2024), 'Predicting buildings' EPC in Italy: a machine learning based-approach', Bank of Italy Occasional Papers No. 850

Brounen, D., and Kok, N. (2011), 'On the economics of energy labels in the housing market', *Journal of Environmental Economics and Management*, Vol. 62, pp. 166-179

Bunten, D. M., Kahn, M. E. (2017), 'Optimal real estate capital durability and localized climate change disaster risk', *Journal of Housing Economics*, Vol. 36, pp. 1-7

Camboni, R., Corsini, A., Miniaci, R., Valbonesi, P. (2021), 'Mapping fuel poverty risk at the municipal level. A small-scale analysis of Italian Energy Performance Certificate, census and survey data', *Energy Policy*, Vol. 155

Camboni, R., Corsini, A., Miniaci, R., Valbonesi, P. (2024), 'CO2 emissions reduction from residential buildings: cost estimate and policy design', University of Padua, Marco Fanno Working Papers No. 304

Cerin, P., Hassel, L. G., Semenova, N. (2014), 'Energy Performance and Housing Prices', *Sustainable Development*, Vol. 22, pp. 404-419

Christensen, P., Francisco, P., Myers, E., Souza, M. (2023), 'Decomposing the wedge between projected and realized returns in energy efficiency programs', *Review of Economics and Statistics*, Vol. 105(4)

Cresme, Symbola, ANCE, European Climate Foundation (2024), "Il valore dell'abitare. La sfida della riqualificazione energetica del patrimonio edilizio italiano", available at: https://portale.assimpredilance.it/uploads/allegati/ricerca_83295_6604238753a37.pdf, accessed 20/11/2024

Curtis, J., Grilli, G., Lynch, M. (2024), 'Residential renovations: Understanding cost-disruption trade-offs', *Energy Policy*, Vol. 192

Daskalaki, E. G., Kontoyiannidis, S., Balaras, C. A., Droutsa, K. G. (2013), 'Energy certification of Hellenic buildings: First findings', *Energy and Buildings*, Vol. 65, pp. 429-437

Davis, L. W. (2023), Heat Pumps: 'Green Tech' That Cuts across the Income Distribution, NBER Working Paper No. 31344

De Blasio, G., Fiori, R., Lavecchia, L., Loberto, M., Michelangeli, V., Padovani, E., Pisano, E., Rodano, M.L., Roma, G., Rosolin, T., Tommasino, P. (2024), 'Il miglioramento dell'efficienza energetica delle abitazioni in Italia: lo stato dell'arte e alcune considerazioni per gli interventi pubblici', Bank of Italy Occasional Papers No. 845

DEI (2024), 'Prezzi informativi dell'edilizia. Recupero, ristrutturazione, manutenzione', available at: https://www.build.it/prezzari/dei/, accessed 20/11/2024

Dolsak, J. (2023), 'Determinants of energy efficient retrofits in residential sector: A comprehensive analysis', *Energy & Buildings*, Vol. 282

Doronzo, R., Siracusa, V., Antonelli, S. (2021), 'Green bonds: the sovereign issuers' perspective', Bank of Italy, Markets, Infrastructures, Payment Systems, No. 3

Droutsa, K. G., Kontoyiannidis, S., Dascalaki, E. G., Balaras, C. A. (2016), 'Mapping the energy performance of 36 Ellenic residential buildings from EPC (Energy Performance Certificate) data', *Energy*, Vol. 98, pp. 284-295

European Banking Authority (2024), 'EBA Report - In response to the call for advice from the European Commission on green loans and mortgages', EBA/REP/2023/38

European Commission (2024), 'Energy Performance of Buildings Directive', available at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en, accessed 20/11/2024

Fabbri, K., and Gaspari, J. (2021), 'Mapping the energy poverty: A case study based on the energy performance certificates in the city of Bologna', *Energy & Buildings*, Vol. 234

Fowlie, M., Greenstone, M., Wolfram, C. (2018), 'Do energy efficiency investments deliver? Evidence from the weatherization assistance program', *The Quarterly Journal of Economics*, Vol. 133(3)

Fregonara, E., Rolando, D., Semeraro, P. (2017), 'Energy performance certificates in the Turin real estate market', *Journal of European Real Estate Research*, Vol. 10, Issue 2, pp.149-169

Fuerst, F., McAllister, P., Nanda, A., Wyatt, P. (2013), 'Energy performance ratings and house prices in Wales: An empirical study', *Energy Policy*, Vol. 92, pp. 20-33

Gangolells, M., Casals, M., Forcada, N., Maraculla, M., Cuerva, E. (2016), 'Energy mapping of existing building stock in Spain', *Journal of Cleaner Production*, Vol. 112, pp. 3895-3904

Gatto, A., Drago, C., Panarello, D., Aldieri, L. (2023), 'Energy transition in China: Assessing progress in sustainable development and resilience directions', *International Economics*, Vol. 176, No. 100450

Gatto, A., and Panarello, D. (2022), 'Misleading intentions? Questioning the effectiveness and biases of Eurobarometer data for energy sustainability, development and transition research', *Energy Research & Social Science*, Vol. 93, No. 102813

Giarda, E., and Panarello, D. (2025), 'The energy efficiency price premium of residential buildings in three Italian regions', *Energy Research and Social Science, https://doi.org/10.1016/j.erss.2025.103932*

Gouveia, J. P., and Palma, P. (2019), 'Harvesting big data from residential building energy performance certificates: retrofitting and climate change mitigation insights at a regional scale', *Environmental Research Letters*, Vol. 14

Hennighausen, H., Liao, Y., Nolte, C., Pollack, A. (2023), 'Flood insurance reforms, housing market dynamics, and adaptation to climate risks', *Journal of Housing Economics*, Vol. 62

Hjortling, C., Bjork, F., Berg, M., af Klintberg, T. (2017), 'Energy mapping of existing building stock in Sweden – Analysis of data from Energy Performance Certificates', *Energy and Buildings*, Vol. 153, pp. 341-355

Immobiliare (2014), 'L'Italia sta invecchiando... e anche le sue case', available at: https://www.immobiliare.it/info/ufficio-stampa/2014/l-italia-sta-invecchiando-e-anche-le-sue-case-1203/, accessed 20/11/2024

Istat (2014), "Paesaggio e patrimonio culturale", in: *Rapporto Bes 2014*, Istat, Rome

Khayatian, F., Sarto, L., Dall'O', G. (2016), 'Application of neural networks for evaluating energy performance certificates of residential buildings', *Energy and Buildings*, Vol. 125, pp. 45-54

Loberto, M., Mistretta, A., Spuri, M. (2023), 'The capitalization of energy labels into house prices. Evidence from Italy', Bank of Italy Occasional papers No. 818

Mata, E., Kalagasidis, A. S., and Johnsson, F. (2015), ‘Cost-effective retrofitting of Swedish residential buildings: effects of energy price developments and discount rates’, *Energy Efficiency*, Vol. 8, pp. 223-237

McCord, M., Haran, M., Davis, P. (2020a), ‘Energy performance certificates and house prices: a quantile regression approach’, *Journal of European Real Estate Research*, Vol. 13, No. 3, pp. 409-434

McCord, M., Lo, D., Davis, P. T., Hemphill, L., McCord, J, Haran, M. (2020b), ‘A spatial analysis of EPCs in the Belfast Metropolitan Area housing market’, *Journal of Property Research*, Vol. 37, No. 1

Mudgal, S., Lyons, L., Cohen, F., Lyons, R., Fedrigo-Fazio, D. (2013), ‘Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries’, Final Report, European Commission (DG Energy)

NGFS (2023), ‘NGFS scenarios technical documentation. Technical report’, Network for Greening the Financial System, Paris, France, available at: https://www.ngfs.net/sites/default/files/media/2024/01/16/ngfs_scenarios_technical_documentation_phase_iv_2023.pdf, accessed 20/11/2024

Otsuka, A. (2018), ‘Regional Determinants of Energy Efficiency: Residential Energy Demand in Japan’, *Energies*, Vol. 11

Otsuka, A., and Goto, M. (2015), ‘Estimation and determinants of energy efficiency in Japanese regional economies’, *Regional Science Policy & Practice*, Vol. 7, No. 2

Pagliaro, F., Hugony, F., Zanghirella, F., Basili, R., Misceo, M., Colasuonno, L., Del Fatto, V. (2021), ‘Assessing building energy performance and energy policy impact through the combined analysis of EPC data – The Italian case study of SIAPE’, *Energy Policy*, Vol. 159

Panarello, D., and Gatto, A. (2023), ‘Decarbonising Europe–EU citizens’ perception of renewable energy transition amidst the European Green Deal’, *Energy Policy*, Vol. 172

Politecnico Milano, Energy & Strategy, Osservatorio Energy Efficiency (2024), *Energy Efficiency Report 2024*, available at: https://www.energystrategy.it/es-download/, accessed 20/11/2024

Streicher, K. N., Padey, P., Parra, D., Burer, M. C., Patel, M. K. (2018), 'Assessment of the current thermal performance level of the Swiss residential building stock: Statistical analysis of energy performance certificates', *Energy & Buildings*, Vol. 178, pp. 360-378

Taruttis, L., and Weber, C. (2022), 'Estimating the impact of energy efficiency on housing prices in Germany: Does regional disparity matter?', *Energy Economics*, Vol. 105

Trotta, G. (2018), 'The determinants of energy efficient retrofit investments in the English residential sector', *Energy Policy*, Vol. 120, pp. 175-182

UPB (2023), 'Audizione della Presidente dell'Ufficio parlamentare di bilancio nell'ambito dell'indagine conoscitiva sugli strumenti di incentivazione fiscale con particolare riferimento ai crediti d'imposta', Ufficio Parlamentare di Bilancio, Rome, Italy