Buildings' energy performance, green attributes and real estate prices: methodological perspectives from the European literature

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Buildings' energy efficiency may affect real estate prices, but the literature suggests that the effects of green attributes and Energy Performance Certificate ratings on the value of residential properties in Europe are still variable across contexts. The adoption of methods able to appropriately investigate this issue is thus essential. In this framework and to support future studies, this paper offers a methodological review of scientific works on the topic published in the last five years. Our work does not only represent an update of other reviews, but it originally analyses the papers by a methodological viewpoint. Results highlight a progressive refinement of the research questions and methods adopted. Then, the increasing importance of concepts such as latent variables and green attributes in the real estate pricing process is detected and identified as a field to be furtherly explored. Finally, Structural Equation Modelling is proposed as a promising approach for future studies.

1. Introduction

Residential buildings' energy consumption represents one of the most relevant sources of CO_2 emissions (Chen and Marmolejo-Duarte, 2019; Manganelli et al., 2019; Wilkinson and Sayce, 2020), and the enhancement of energy efficiency has progressively become of paramount importance, as shown for instance by the 2015 UN Sustainable Development Goal 7 – Affordable and Clean Energy, target 7.3, which recommends doubling the global rate of improvement in energy efficiency by 2030 (United Nations General Assembly, 2015).

At the European level, the EU has started to systematically tackle the issue since the early 2000s, with the release of the first Energy Performance of Buildings Directive in 2002 (EPBD-Directive 2002/91/EC). Then, subsequent updates (EPBD-Directive 2010/31/EU; EPBD-Directive 2018/844/EU) and integrations (Commission Delegated Regulation EU, n. 244/2012) aiming at reinforcing and improving the framework have progressively followed.

The urgency of the environmental matter, combined with the enduring existence of a certain slowness in the performance of energy interventions, have recently led the European Commission to strengthen its commitment towards the achievement of a real "green" transition: in fact, the Communication presented from the Commission to the European Parliament on 10th October 2020 and named *"A Renovation Wave for Europe – greening our buildings, creating jobs, improving lives"* (European Commission, 2020) puts at its core a faster and deeper energy

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renovation of buildings. Moreover, as outlined by the title of the Communication, in the current socio-economic framework – which has been strongly affected and weakened by the Covid-19 pandemic – energy retrofit and green constructions are valued not only as necessary actions for decarbonization but also as economic leverages: this is a statement that thus contributes to possibly increase the market value of these buildings.

As underlined by scholars and experts in the field, consumption patterns of domestic energy are a multi-dimensional issue involving variables such as climate zones (Chiesa and Fregonara, 2019; Dell'Anna et al., 2019; Fregonara et al., 2020; Taltavull de La Paz et al., 2019), architectural and technological characteristics of the residential units, households' income, behavioural, demographic and socio-economic characteristics of inhabitants (Azizi et al., 2019), cost of energy, fuel and combustive agents and so on (Kamal et al., 2019).

In this framework, the implementation of measures able to address multiple variables can probably represent the most sustainable solution to reach the desired goals; however, it is nonetheless important to underline that the reduction of domestic energy consumption related to heating and cooling needs can be particularly facilitated by: a) retrofit interventions for what concerns the historical and existing housing stock; b) construction of "green" and nearly-zero energy buildings (D'Agostino and Mazzarella, 2019) for what concerns new real estate properties. Technical interventions that aim to improve buildings' energy efficiency include, for instance, thermal coating, solar panels, photovoltaic systems and storage cells, use of insulating materials on horizontal, vertical and oblique perimetral surfaces, installation of energy-efficient windows, doors and skylights, heat pumps, floor heating and cooling, combination with domotics and remote-control systems, etc. (Manganelli et al., 2019). Additionally, it must be mentioned that the upscaling of green policies and energy consumption reduction from the building to the urban and district-based scale has started to emerge (Reynolds et al., 2017).

With exclusive reference to the building level, the implementation of the technical solutions mentioned above usually implies a considerable initial expenditure by households, and in absence of monetary incentives and financial mechanisms the economic viability of these interventions cannot be taken for granted (Brown et al., 2019). However, it is known that these interventions are associated to different and multiple benefits (Kamal et al., 2019; Kerr et al., 2017), such as an enhanced indoor environment (e.g., in terms of thermal comfort, ventilation, acoustic insulation, aesthetics, etc.), lower CO_2 emissions, and also lower heating and cooling running costs during the entire lifecycle of the building. Consequently, it has been advanced that energy efficient houses might thus be desirable by owners, occupants and potential buyers also by an economic point of view.

Given these multiple benefits and considering that – especially for what concerns the existing residential stock – sellers might want to recoup previous expenditures, it has frequently been supposed that energy efficient residential units are associated to higher real estate prices. In other words, it has thus been advanced that higher energy efficiency has a positive effect on properties' values.

However, even though this hypothesis sounds strong and reasonable, the international literature on the topic has not reached an agreement yet (Bisello et al., 2020; Cespedes-Lopez et al., 2019; Marmolejo-Duarte and Chen, 2019; Wilkinson and Sayce, 2020). More precisely, the appreciation of buildings' energy performance and "green" attributes by the real estate market still appears not homogeneous across contexts, and the relationships between energy-related characteristics and residential real estate prices have not proved to be straightforward up to now (McCord et al., 2020b). In fact, despite the increasing attention towards this topic and the progressive growth of scientific articles addressing the issue, results obtained by scholars have been extremely variable (Cespedes-Lopez et al., 2019; Marmolejo-Duarte and Chen, 2019; Wilkinson and Sayce, 2020). This lack of uniformity may be related to contextual factors (e.g., country, location and climate zone in which the buildings are located) and to specific characteristics of the local real estate markets and stocks (e.g., type of buildings, market segments, specific level of energy efficiency considered, etc.). Additionally, it must also be recalled that the measurement of buildings' energy performance is still not consistent throughout EU Member States and that the research perspectives and methods adopted by existing studies may have overall contributed to the variability of the results. Moreover, it is worth mentioning that the situation is constantly evolving, also depending on the incentives, regulatory frameworks and economic measures set up by governments especially in this time of economic crisis. In fact, it is possible that, while the compliance with energy requirements becomes stricter, Governments facilitate retrofits through economic incentives, the awareness about the advantages of energy-efficient buildings increases and the sensitivity towards ecological matters spreads, real estate prices will be affected too.

With respect to green policies promoted at the EU level, the European Green Deal – i.e. a set of policies aiming at making Europe the first net-zero climate impact continent – represents the framework of reference, and significantly it will be financed by one third of the 1.8 trillion euros of the Next Generation EU Recovery Plan and the EU's seven-year budget (European Commission, 2021a). For what concerns single EU countries, an exemplificatory case can be mentioned. For instance, Italy established the so called "Superbonus" (law n. 77, July 2020) during the 2020 Covid-19 crisis, to favour both economic recovery and the achievement of green objectives: in fact, the "Superbonus" encourages the performance of retrofits on buildings respecting given characteristics leveraging on fiscal and economic incentives. However, not only emergency measures but also long-term strategies and action plans have been developed by single EU countries, as recently outlined and analysed by a working document elaborated by the European Commission staff (European Commission, 2021b).

In this framework and through the conduction of a systematic analysis of the most recent peer-reviewed literature, this paper aims to identify the research methods adopted by scholars to explore the relationships between energy efficiency and real estate prices, in order to:

a) provide a methodological overview useful for future applications;

b) detect the research lines and methodological approaches that seem particularly worth exploring through future studies;
c) possibly recognize additional methods that may be particularly suitable to face emerging and promising research issues.

This contribution will take into account only the European context: in fact, whilst different conditions and regulatory frameworks possibly influencing markets and behaviours exist worldwide, the European Union has progressively established for its Member States a set of common directives, as anticipated above. Even though full comparability among EU countries is not possible yet, these Directives nonetheless offer a homogeneous policy background.

Given that in the European context the official document that expresses the energy efficiency degree of a building/building unit is the Energy Performance Certificate (EPC), the literature review will mainly include contributions that investigate the relationships between EPC ratings and real estate prices.

Notice that the work makes reference to the measures taken at the building level to ensure energy efficiency. However, as mentioned above, policies are also shifting attention to other urban and district-based solutions to reach the targets. The reasoning about the potentialities offered by shifting from the single building to the district/territorial scale is interesting, particularly in the case, for example, of the coexistence of different energy sources and technologies for supplying it. The great complexity deriving by enlarging the context can be managed through the definition of policies for the territorial governance and for the energy consumptions reduction, opening the way to other experiences and researches, mainly involving the application of approaches for the evaluation of project energy-economic sustainability (De Paola et al., 2021; Del Giudice et al., 2021a; Del Giudice et al., 2021b). Thus, the present work will focus on the building scale, demanding to future studies the exploration of other scale perspectives.

Overall, this piece of work explores the most recent studies on EPCs and real estate prices by a methodological viewpoint, and it can serve both as a literature review in itself and as a methodological support for further studies that will aim to estimate the effects of energy efficiency on real estate prices. Overall, our work does not only represent an update of previous literature review studies, but it originally analyses the papers by a methodological viewpoint.

The paper is articulated as follows. Section 2 presents a short overview about buildings' energy efficiency and EPCs in EU, as to frame the context of analysis and recall the regulatory framework that is determining energy-related policies in EU countries; in this Section some references to the Italian context are performed too, to empirically exemplify some concepts and applications of the EU Directives. Section 3 describes the materials and methods, while Section 4 illustrates and discusses the selected contributions and obtained results. Finally, Section 5 outlines final remarks and proposes perspectives for future studies.

2. Background: a short overview on the European Union's regulatory framework and policies about buildings' energy efficiency

In order to boost decarbonisation and the green energy transition in the real estate sector, the European Union has released and progressively updated the Energy Performance of Buildings Directive (EPBD-Directive 2002/91/EC). Originally issued in 2002 and then modified with subsequent versions (EPBD-Directive 2010/31/EU; EPBD- Directive 2018/844/EU) and supplements (Commission Delegated Regulation (EU) n. 244/2012), the EPBD has not only introduced minimum energy performance requirements for buildings but it has also established that buildings' energy efficiency is measured and attested by an Energy Performance Certificate (EPC). The EPDB prescribes that an EPC is made available whenever buildings are constructed, sold or rented out (Bisello et al., 2020): in fact, the provision, communication and publication of EPC ratings enhance transparency during transactions of various kinds and they offer precious information to the subjects involved in the operations (e.g., seller, buyer, tenant, intermediaries, etc.).

As known, EPCs summarise the energy efficiency of buildings through a rating scheme; with reference to a country such as Italy, energy labels range for instance from A4 (very efficient) to G (inefficient). Additionally, the EPC also includes suggestions on the technical interventions to be performed to improve the current rating of the building/building unit under consideration. With the aim of improving the rating scheme, the original criteria at the basis of the EPC rating were modified in 2018 (EPBD- Directive 2018/844/EU), and changes have been integrated by Member States in their national legislations in subsequent years.

Then, *"A Renovation Wave for Europe"* (European Commission, 2020) has recently anticipated that further enhancements to the EPC framework will be needed shortly. In fact, the document has underlined that barriers to the energy renovation of buildings exist at several points of the value chain, and that the poor explanation and understanding of the benefits stemming from retrofit (including their measurement and monetisation) definitely represent a major obstacle to renovation. Consequently, the European Commission has identified, among the essential areas of intervention, the strengthening of information, legal certainty (and incentives) for public and private owners and tenants. More precisely, the Commission will revise the EPBD in 2021, and it will propose to *"introduce a stronger obligation to have Energy Performance Certificates alongside a phased introduction of mandatory minimum energy performance standards for existing buildings […]. The impact assessments accompanying these legislative revisions will consider different options in terms of the level, scope and timing of these requirements"* (European Commission, 2020, p. 5).

Moreover, the European Commission will not only propose mandatory minimum energy performance standards as part of the revision of the EPBD by the end of 2021, but it will also propose to update the EPC framework, e.g. encouraging the application of energy performance metering technologies, the creation of a uniform EU machine-readable data format for the EPCs, the improvement (in terms of both availability and accessibility) of EPCs digital repositories and the

possible extension of energy audits requirements to a larger variety of non-residential buildings.

Coherently with the EU guidelines, a European country such as Italy has for instance started to make EPCs mandatory since 2009; additionally, in line with EU directives, the publication of the EPC rating has become compulsory in real estate advertisements since 2012 (Fregonara et al., 2017). The contents of the EPBD 2018 were adopted just recently instead, with the Decreto Legislativo 10/06/2020, n. 48. With reference to repositories publicly available, an overview of the number of EPCs progressively issued and of associated ratings can be currently freely accessed on the SIAPE- Sistema Informativo sugli Attestati di Prestazione Energetica website (https://siape.enea.it/). As mentioned in the Introduction, other EU countries have developed frameworks and long-term strategies promoting buildings' energy efficiency too.

Overall, the growing relevance of the topic at the international level has favoured the flourishing of a significant amount of studies focusing on buildings' energy efficiency, including contributions that aim to analyse the effects of EPCs and single "green" attributes on residential real estate prices. Recent articles have provided comprehensive overviews on the state of the art (Bisello et al., 2020; Khazal and Sønstebø, 2020; Marmolejo-Duarte et al., 2020; Marmolejo-Duarte and Chen, 2019), but the literature on the topic is still proliferating, and numerous articles have been published in the last few years. To pursue the research objectives outlined in the Introduction, the rest of the article will investigate the methods and results stemming from a systematic review of the most recent peer-reviewed contributions on the topic.

3. Materials and methods

The aim of this piece of work is to highlight the methodological perspectives recently adopted by scholars to investigate the relationships between buildings' energy performance and real estate prices. In order to reach this goal and capture the most updated methodological approaches, we performed a structured literature review, focusing only on scientific works indexed on the Scopus database and published in the last 5 years, i.e. between 2016 and 2020. This time frame was selected since it is a timespan frequently adopted in literature review studies aiming at investigating the recent state of the art on a defined topic (see, for instance, Tavares Thomé, 2016). Additionally, considering that EU Member States have integrated the prescriptions of the EPBD 2010 – which makes EPCs mandatory for all European buildings (Barreca et al., 2021) – at a different pace, we supposed that the articles published in this timeframe could most likely capture the effects of the energy efficiency regulations on the real estate markets better than less recent studies.

For the years 2016-2017 we capitalized on the searches already conducted by other authors (Bisello et al., 2020; Khazal and Sønstebø, 2020; Marmolejo-Duarte et al., 2020; Taltavull de La Paz et al., 2019), who recently integrated a literature review section in their empirical works: on the basis of their results, appropriate

contributions were thus included in our analysis. With respect to previous studies, our work does not provide an in-depth analysis of a single method (e.g. regression, spatial analysis, etc.), but rather a more comprehensive review of the methodologies recently adopted by scholars in the analysed literature.

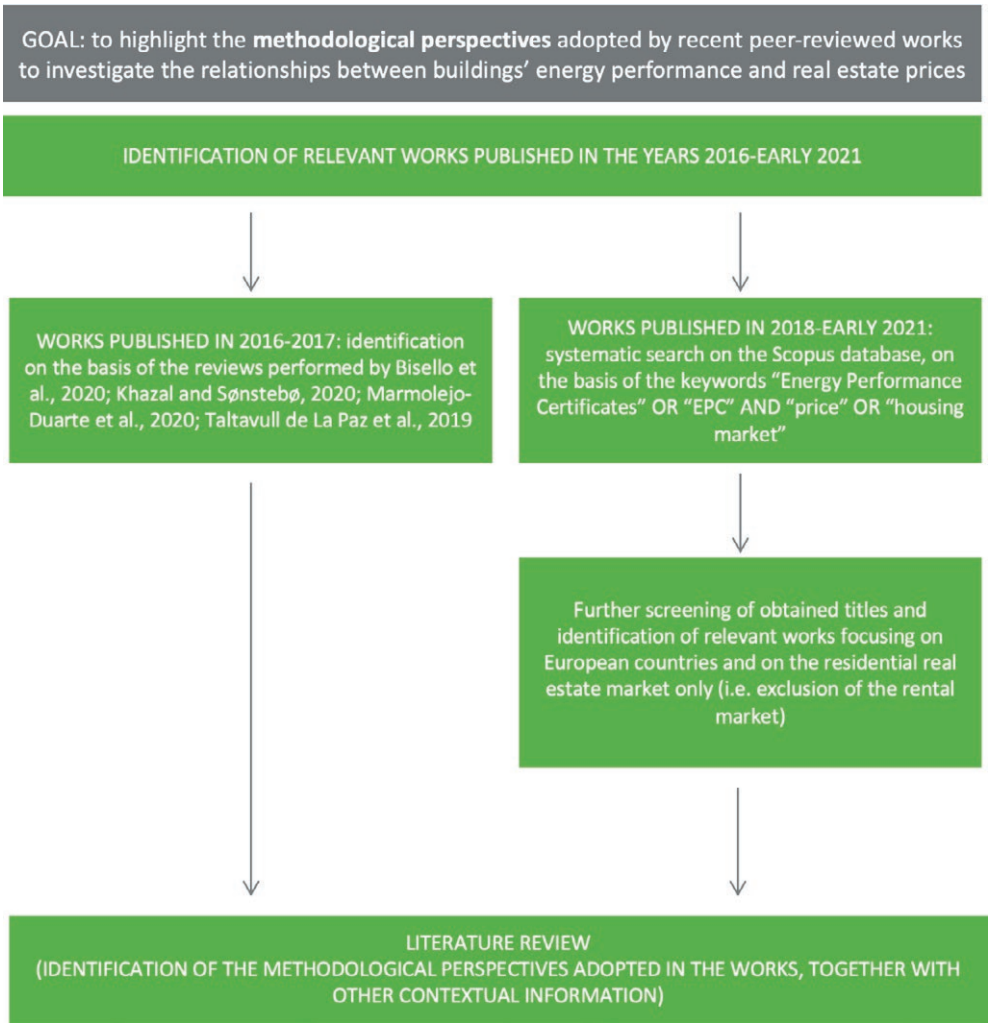
For what concerns the years 2018-2020, an original and *ad hoc* search was performed instead. In line with the work of other researchers (Bisello et al., 2020), we retrieved on-topic contributions through a systematic search on the Scopus database (https://www.scopus.com, last accessed on 31st January 2021), inputting as keywords "Energy Performance Certificates" OR "EPC" AND "price" OR "housing market". This initial search returned more than 120 contributions. Obtained titles were then screened, and only articles focusing on the European context and on the effects of EPC/ "green" attributes on the residential real estate market were selected for analysis. Given that the focus of the study is the residential real estate market, articles concerning EPCs and the rental sector (Bian and Fabra, 2020; Cajias et al., 2019; Chegut et al., 2020; Collins and Curtis, 201; Cornago and Dressler, 2020; Franke and Nadler, 2019; Fuerst et al., 2020; Heffernan et al., 2021; Khazal and Sønstebø, 2020; Pommeranz and Steininger, 2021) were thus not included in the review. However, they represent an interesting and emerging field of research and they could constitute the core of a specific contribution on the topic. Articles focusing on the cost-effectiveness of the interventions or on contexts other than Europe (see, for instance, Baldini et al., 2020 and Dell'Anna and Bottero, 2021 respectively) were not analysed as well. Articles that during the screening phase emerged as useful for the contextualisation of the debate (e.g. articles analysing the willingness to pay for specific green interventions and attributes) are nonetheless cited in the text (see, for instance, Aydin et al., 2019, D'Alpaos and Bragolusi, 2020; Marmolejo-Duarte et al., 2020d).

Finally, some contributions published in early 2021 and/or presenting 2021 as publication year but already available in late 2020 were included in the analysis, with the aim of providing the most updated state of the art. Figure 1 provides an overview of the workflow followed to conduct the study.

Coherently with the research objectives outlined in the Introduction, it was decided to analyse the selected contributions according to the following fields*: a) city and country of application; b) size of the data sample; c) timeframe to which the data analysed in the contributions referred to; d) type of real estate price under investigation; e) methods adopted by researchers to conduct the study; f) synthesis of major findings*.

The fields *a), b)* and *c)*, together with the reference to the contribution in the form Author-Year, mainly aimed at contextualising the study (e.g., by a geographic and temporal perspective, as well as at specifying the data under study). *d)* aimed at identifying the type of price considered by authors: in fact, prices are not only a very important variable (since in most cases they constitute the dependent variable), but they are also an object of debate in the estimative discipline (Curto et al., 2012). Consequently, it was deemed appropriate to specify their nature through a dedicated field. Even though some authors used the log version of prices, this was not specified in the analysis. *e)* aimed at identifying the methods adopted by researchers and it represents the core of the study. Field *f)* was

Figure 1. Workflow followed to perform the literature review presented in the study.



Source: authors' own elaboration.

included to offer a synthesis of the major findings, without the claim of providing a complete account of all the results reported in the contributions.

Information was overall summarised into a table and then analysed according to the research questions of our study.

4. The influence of Energy Performance Certificates (EPCs) on real estate prices: results from recent studies

Coherently with the methods described in the previous section, a total of 26 contributions were included in the review. Table 1 functions as reference for the analysis and it provides a systematic synthesis of the information collected.

4.1 Location, geographic scale, property types and sample sizes

The examined contributions covered different European countries, ranging from Mediterranean to Northern and Eastern Europe (Figure 2). More precisely, 7 studies analysed Italian cities, 7 addressed Spanish contexts, 3 focused on Belfast (Northern Ireland), 2 on Sweden, 1 on Portugal, 1 on Wales, 1 on Denmark, 1 on Finland (Helsinki area), 1 on Oslo (Norway), 1 on Dublin (Ireland) and 1 on Bucharest (Romania); additionally, one study included a desk review of EU case-studies (Figure 2). The recent publication of papers focusing on Mediterranean countries seems to indicate that a certain gap in the literature evidenced by other scholars (Dall'Anna et al., 2019) – i.e. the prevalence of studies focusing on Northern Europe – has started to be at least partially reduced. However, the results stemming from our research highlighted that a certain unbalance in the literature still exists, since not all EU countries were equally represented in the works emerged from the application of the workflow described in Section 3.

Overall, the geographic scale selected by authors varied: the urban (i.e. single cities), intra-urban (i.e. sub-portions of cities), metropolitan (i.e. main city and surrounding municipalities), territorial (e.g. province) and national (i.e. country) scales were overall explored. Additionally, a couple of studies considered two cities as object of analysis, especially to perform comparisons (Dell'Anna et al., 2019; Manganelli et al., 2019).

In line with the object of the research, all articles analysed residential units. However, some exclusively focused on apartments located in multi-family buildings (Chen and Marmolejo-Duarte, 2019; Cespedes-Lopez et al., 2020; Dell'Anna et al., 2019; Fuerst et al., 2016b; Marmolejo-Duarte, 2016; Marmolejo-Duarte and Chen, 2019; Marmolejo-Duarte et al., 2020; Taltavull et al., 2017), whereas others exclusively considered single family-houses (Jensen et al., 2016; Wahlström, 2016; Wilhelmsson, 2019). Choices were usually justified by authors in light of the characteristics of the local housing stock (i.e. most frequent type of building).

Sample sizes varied too, and they seemed to depend both on specific research questions and available datasets. Considered timeframes were not homogeneous as well, and they ranged from one or few months to several years. Contributions usually included in the analysis datasets referring up to 2-3 years before publication, even though some studies analysed older (Evangelista et al., 2020; Fuerst et al., 2016b; Jensen et al., 2016; Marmolejo-Duarte and Chen, 2019; Marmolejo-Duarte et al., 2020; McCord et al., 2020; Wahlström, 2016) or more recent data (Bottero et al., 2018; Dell'Anna et al., 2019).

Table 1. Recent articles that analyse the influence of "green" variables and EPC ratings on residential real estate prices: background, methods and main findings.

Authors and year	City and country	Data sample: size	Data sample: year	Price type included in the models	Methods	Major findings
Barreca et al., 2021	Turin (Italy)	2,092 residential units	2015-2018	Listing prices	Hedonic Price Model (OLS), Spatial Error Models	The study pointed out that low EPC ratings (i.e. E, F and G) significantly and negatively affected housing prices; high EPC ratings (i.e. B, A1, A2, A3 and A4) had a lower but positive influence instead. Then, the building category and the housing unit maintenance level resulted to particularly influence prices. With reference to the spatial dimension, different spatial clusters resulted to behave as different sub-markets. With respect to previous studies (Fregonara et al, 2014; Fregonara et al., 2017), price premiums increased.
Bisello et al., 2020	Bolzano (Italy)	849 residential units	March 2018	Listing prices	Hedonic Price Model (OLS), then combined with spatial specifications	All other characteristics being equal, authors found a price premium in excess of 6% moving from the worst EPC rating ("G") to the best ("A"). A spillover effect exerted by retrofitted properties on nearby properties was detected too.
Bottero et al., 2018	Turin (Italy)	15,295 residential properties	2015- Q1 2018	Listing prices	OLS, Multiplicative exponential model, Linear and nonlinear spatial error model, Linear and nonlinear spatial autoregressive model	Through a variety of models combining the OLS-Hedonic Price Model and spatial econometrics, authors estimated the willingness to pay for a specific type of residential unit characterized by "E" EPC rating. Additionally, authors underlined that level of maintenance plays an important role in the price formation process.
Cespedes-Lopez et al., 2020	Province of Alicante (Spain)	52,939 observations (multi-housing properties), of which, 9,194 included information on energy qualification	Period June 2017 – May 2018	Listing prices	Hedonic Price Model (OLS)	The study highlighted that, for the multi-family housing properties under study, a positive relationship between EPC ranking and listing prices did not exist.
Chen and Marmolejo-Duarte, 2019	Barcelona Metropolitan Area (164 municipalities) (Spain)	3,246 apartments for 2014 and 3,246 apartments for 2016 (total: 6,492)	2014-2016	Listing prices	Spatial Error Hedonic Model	Price premiums were found for "A" ranked homes in 2014 and "B, C, D" ranked homes in 2016. Additionally, authors highlighted that "A" ranked homes located in peripheries where new completions were developed; "B", "C" and "D" were found in more central locations in neighbourhoods of wealthy population, instead.

Authors and year	City and country	Data sample: size	Data sample: year	Price type included in the models	Methods	Major findings
Dell'Anna et al., 2019	Barcelona (Spain) and Turin (Italy)	3,224 (Barcelona) and 15,288 (Turin) apartments mainly in multi-family buildings	2014-2018	Listing prices	Hedonic Price Model (OLS), then combined with spatial specifications	Authors found that in Barcelona each step of EPC ranking allowed a + 2% in the total listing price, with an increase of 12% passing from a rank G to A. In Turin, the found percentage was +6.8% instead. Then, the correction of the spatial autocorrelation allowed to improve the model fitting: corrected percentages were 1.88% for Barcelona and 6.33% for Turin.
Evangelista et al., 2020	Portugal	256,000 residential properties	2009-2013	Sales prices	Hedonic Price Model and quantile regressions	Authors found a price premium for energy efficiency, which was more pronounced for apartments (13%) than for houses (5 to 6%). Additionally, these price premiums tended to increase from 2009 to 2013.
Fregonara et al., 2017	Turin (Italy)	879 transactions of old properties	2011-2014	Transaction prices and listing prices	Hedonic Price Model (OLS)	Authors highlighted that EPC labels had no impact on prices of apartments in old buildings, which were characterized by mid-to-low energy performance.
Fuerst et al., 2016a	Wales	191,544 transactions	2003-2014	Transaction prices	Hedonic Price Model (OLS)	The study highlighted a positive price premium for EPC rating A/B (+12.8%) compared to dwellings rated D. Statistically significant discounts were found for E and F ratings instead (-3.6% and -6.5 %, respectively).
Fuerst et al., 2016b	Helsinki metropolitan area (Finland)	6,203 observations (apartmentsonly)	2009-2012	Transaction prices	Hedonic price Model (OLS)	A statistically significant 3.3% price premium for apartments in the top three energy-efficiency categories was found. This percentage amounted to 1.5% when a set of detailed neighbourhood characteristics were included.
Jensen et al., 2016	Denmark	A sample derived from delimitations applied to a total of 117,483 observations (single-family houses)	1st January 2007-1st July 2010; 1st July 2010-October 2012	Sale prices	Regression analysis	Authors found that EPC rating had an impact on sale prices. Before the implementation of the EPBD in 2010 the effect was modest, but it increased significantly in the period 2010-2012.

Authors and year	City and country	Data sample: size	Data sample: year	Price type included in the models	Methods	Major findings
Manganelli et al., 2019	Bari and Acri (Italy)	101 real estate units located in the central area of Bari, 43 in the suburban area of Bari and 39 in Acri	Recent years	Purchase and sale prices	Categorical regression – Alternating Least Squares Model	Authors found that in the most valuable areas (e.g. city centre of Bari) energy efficiency plays only a secondary role in the value formation process, whilst location is of primary importance. For what concerns the increase of value when shifting from a lower EPC rating to the next, authors found that the last jump (i.e. from B to A) was the one evaluated by the market as the most important.
Marmolejo-Duarte, 2016	Metropolitan area of Barcelona (Spain)	4,248 apartments (multifamily dwellings)	2014	Listing prices	Hedonic Price Model (OLS)	The study highlighted that an improvement from an EPC G rating to an A rating increased the value by 5.11 %.
Marmolejo-Duarte and Chen, 2019	Municipalities around the Barcelona area (Spain)	3,479 apartments (multifamily dwellings)	First quarter of 2015	Listing prices	OLS, also applied to different clusters of apartments (i.e. market segments)	EPC rating affected older dwellings, while it played a null role in the price formation for apartments with amenities and active-comfort systems. "A" rating exerted a +12.2% price premium for the most expensive, central and well-endowed segment and an impact of + 33.2% for the cheaper segment (apartments with worse active air conditioning, poor architectural quality and located in working-class neighbourhoods).
Marmolejo-Duarte et al., 2020	Municipalities around the Barcelona area (Spain)	5,497 apartments	April 2016	Listing prices	OLS and Geographically Weighted Regression	Authors found a premium equal to 1.7% for each EPC ranking. By a spatial perspective, apartments registering the largest impact of energy efficiency were located in peripheral areas mainly populated by medium and low-income residents and characterized by a less-differentiated housing stock (with respect to wealthier areas).
McCord et al., 2020	Belfast (Northern Ireland)	1,478 properties	Q3 2013-Q3 2014	Transacted prices	OLS, Geographically Weighted Regression and Spatial Lag Model	Different EPC effects were detected with regard to different property types, age of construction and location. Authors found that a capitalization effect was not always present, since high prices did not always connotate superior energy efficiency. Additionally, authors found a composite effect of EPC and heating type (gas heating), underlining that the actual impact of EPC on prices need to be evaluated carefully.

Authors and year	City and country	Data sample: size	Data sample: year	Price type included in the models	Methods	Major findings
McCord et al., 2020a	Belfast (Northern Ireland)	3,797 residential achieved sales	Q3 2017- Q3 2018	Transacted prices	Binary logit regression models in conjunction with a Polytomous Universal Model	Authors did not find evidence of an increased probability of a growth in sales price with higher EPC rating. Overall, results seemed to suggest the presence of a complex and dynamic relationship between the nature of the property type (i.e. apartments, terrace houses, detached and semi-detached houses, etc.) and its energy efficiency and sales price.
McCord et al., 2020b	Belfast (Northern Ireland)	1,478 residential achieved sales	Q2 2018-Q1 2019	Transacted prices	OLS and Quantile Regressions Models	Authors found that the effects of EPC-ratings were not constant or significant across the entirety of the pricing structure, with premiums existing in the higher EPC-rated properties at the higher levels of the price distribution. Authors identified potential EPC scores as a variable affecting market values too.
Morano et al., 2020	Bari (Italy)	200 residential properties	2016-2017	Selling prices	Evolutionary Polynomial Regression	"Extreme" labels (i.e. A and G) exerted the highest contribution on selling prices: whereas label A had a positive effect on prices (+ 27%), G had an approximately similar but negative effect (- 27%).
Olaussen et al., 2017	Oslo (Norway)	Residential properties	1st January 2000-31st December 2014 (EPC mandatory since 1st July 2010)	Transaction prices (bidding context)	Hedonic Price Model (OLS)	Authors found that price premium was not related to EPCs. They also evidenced the problem of omitted variables being correlated with the energy label. Authors hypothesized a correlation between EPC and aesthetics too.
Stanley et al., 2016	Dublin (Ireland)	Residential homes	2009-2014	Listing prices	Hedonic Price Model (OLS)	Authors estimated that a 1-point improvement in the 15-point scale from G to A1 yields a list price increase of 1 %.
Taltavull et al., 2017	Bucharest (Romania)	16,443 observations (apartments)	2013-2015		Hedonic Price Model (OLS) and STAR GLS model	Authors found that energy efficiency is associated to a price premium in two (out of 5) areas of the city. The estimated green premium for the overall city is +3.5%.
Taltavull de La Paz et al., 2019	Alicante (Spain)	Around 9,000 residential properties	Since 2013	Listing prices	Pool- OLS and Instrumental Variables Hedonic Models	Authors found a partial green premium when energy-efficiency improvements increase the EPC rating from G to F (+1.8%) and from F to E (+1.1%). Additionally, different green premiums were found for properties located in different climatic areas, with intermediate zones manifesting the highest green premium.

Authors and year	City and country	Data sample: size	Data sample: year	Price type included in the models	Methods	Major findings
Wahlström, 2016	Sweden	77,000 observations (single-family homes)	2009-2010	Selling prices	Hedonic Price Model (OLS)	Authors found a price premium for housing attributes that improve the energy efficiency and not for energy consumption in itself.
Wilhelmsson, 2019	Sweden	More than 100,000 single-family housing	2013-2018	Transaction prices	Hedonic Price Model and quintile regression; spatial autoregressive models	The author found that the price difference between the A-C EPC labelled houses and the D-G labelled group was small and not statistically significant. Additionally, EPC impact on prices was found for all housing price segments; the impact percentage was almost the same for all segments. Impact was higher in Northern parts of the country instead.
Wilkinson and Sayce, 2020	EU-based case studies	Desk review of 21 contributions	2008-2020	Mostly listing prices	Mostly Hedonic Price Analysis (OLS)	Energy efficiency (expressed through EPC ratings) has started to impact on value, but it is small compared to other value drivers. Additionally, empirical findings seemed to point towards the emergence of a "brown" discount rather than a green premium, especially in the long-term trend.

Figure 2. Effects of EPC ratings on real estate prices in Europe: countries covered by recent peer-reviewed articles.

Source: authors' own elaboration.

4.2 Price types

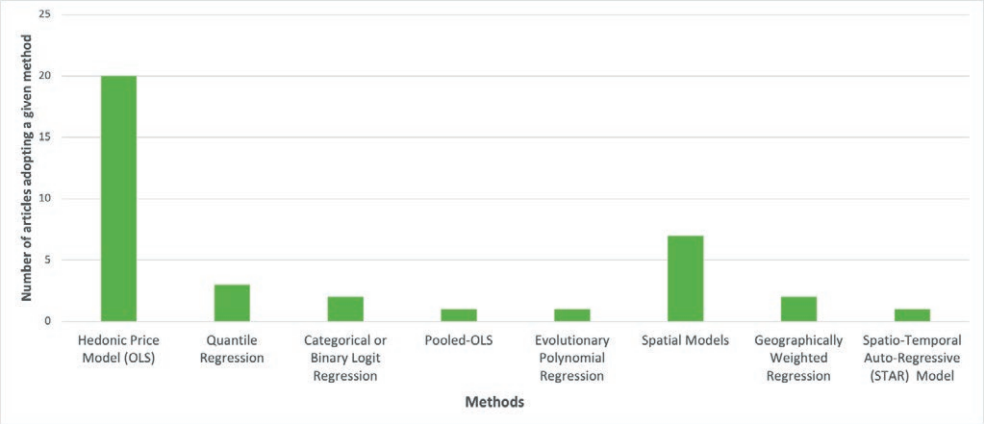
With reference to prices, the selected articles largely considered listing prices. In fact, as known, listing price is frequently the only variable that stands for the value of the real estate asset that can be easily accessed (e.g. through real estate agencies and online real estate portals). Since some studies have underlined that they can be considered as a proxy for actual transaction prices (Curto and Fregonara, 2012; Malpezzi 2003 in Stanley et al., 2016) and that they play an important role in price prediction (Knight, 2002 and Horowitz, 1992 in Barreca et al., 2021),

they are an appropriate variable to be analysed. However, it might be useful to remind that listing prices are especially able to reflect the value of the residential unit as either perceived by the seller or calculated by the intermediary: they thus particularly report the point of view of the offer/supply side (Taltavull del la Paz et al., 2019). Conversely, actual transaction prices are the result of a negotiation process, and they might better reflect not only the value of the residential units and of its characteristics (including "green" variables) as estimated by the supply side, but also the value attributed by the demand side. Thanks to the availability of specific data sources, a certain number of articles was nonetheless able to analyse transaction prices (Fregonara et al., 2017; Fuerst et al., 2016a; McCord et al., 2020; McCord et al., 2020a; McCord et al., 2020b; Whilelmsson, 2019). Interestingly, one article included transaction prices derived from a perfectly competitive bidding context, where potential *"buyers compete with open bids, and the highest wins the auction"* (Olaussen et al., 2017, p. 248). Other authors considered speed of sale (Aydin et al., 2019) and time on the market (Fregonara et al., 2017; Fuerst et al., 2016b) as dependent variable instead; even though the investigation of these variables is out of the scope of this review, it can be stated that they are particularly interesting too, since they suggest to what extent the characteristics of the residential unit are able to meet the demand's needs.

4.3 Methods and major findings

With reference to the methods and models adopted, the selected contributions included the following ones: Hedonic Price Model (Cespedes-Lopez et al., 2020; Fregonara et al., 2017; Fuerst et al., 2016a; Fuerst et al., 2016b; Marmolejo-Duarte, 2016; Olaussen et al., 2017; Stanley et al., 2016; Wahlström, 2016; Wilkinson and Sayce, 2020), OLS and quantile regression (Evangelista et al., 2020; McCord et al., 2020b; Whilhelmsson, 2019), Pooled-OLS and Instrumental Variables Hedonic Models (Taltavull de La Paz et al., 2019), regression (Jensen et al., 2016) and multivariate analysis (Brounen et al., 2020), categorical regression (Manganelli et al., 2019), binary logit regression models in conjunction with a Polytomous Universal Model (McCord et al., 2020a), Evolutionary Polynomial Regression (Morano et al., 2020), Hedonic Price Model (HPM) combined with spatial specification (Barreca et al., 2021; Bisello et al., 2020; Bottero et al., 201; Dell'Anna and Bottero, 2021; Dell'Anna et al., 2019), Geographically Weighted Regression (Marmolejo-Duarte et al., 2020; McCord et al., 2020) and spatio-temporal autoregressive models (Taltavull et al., 2017). Overall, HPM and regressions frequently remain the core of the methods adopted – in line with what already noted by other researchers (Molina et al., 2019) – even though many studies have applied approaches that represent an evolution of the basic OLS approach (Figure 3). For instance, spatial approaches aim to take into account into regressions possible spatial autocorrelation patterns, and they can generally take the form of either Spatial Lag Models or Spatial Error Models. In the considered context of application, quantile regressions usually aim at detecting different EPC effects on price distributions instead.

Figure 3. Methods adopted by recent peer-reviewed articles investigating the effects of EPC ratings on real estate prices in Europe: frequencies.



Source: authors' own elaboration.

The well-established Hedonic Price Method (HPM-OLS) (Curto and Fregonara, 2019; Fregonara et al., 2014; Fregonara et al., 2017; Molina et al., 2019) was applied for instance by M. F. Cespedes-Lopez and colleagues (Cespedes-Lopez et al., 2020); interestingly, these authors found that a positive relationship between EPC-labels and prices did not exist for multi-family properties in the province of Alicante (Spain), and that sellers tended not to disclose the EPC label of the property. This phenomenon was interpreted by authors in light of a variety of reasons, including the following ones: owners' desire to sell their energy-inefficient properties at prices similar to "greener" comparable assets, lack of sanctions for owners not disclosing EPC ratings, absence of compensations for the investments required to improve EPC rating, and a generalized negative attitude towards interventions aimed at improving energy efficiency.

HPM was also applied in a study investigating the Welsh real estate market (Fuerst et al., 2016a): in this case authors highlighted a positive price premium for A/B ratings (+12.8%) compared to dwellings rated D. Statistically significant discounts were found for E and F ratings instead (- 3.6% and – 6.5 %, respectively).

The employment of the HPM to the metropolitan area of Helsinki (years 2009-2012) pointed out a statistically significant + 3.3% price premium for apartments in the top three energy-efficiency categories, reduced to 1.5% when considering detailed neighbourhood characteristics (Fuerst et al., 2016b).

Regression and OLS allowed other authors too to identify various premium prices for residential units characterized either by a certain energy efficiency level (Jensen et al., 2016; Marmolejo-Duarte, 2016; Stanley et al., 2016) or by housing attributes that improve the energy efficiency (Wahlström, 2016).

Analysing through the HPM approach a Norway real estate dataset covering the 2000-2014 period, some researchers did not find a price premium related to

EPCs instead. Interestingly, they also evidenced the problem of omitted variables being correlated with the energy label. Authors then hypothesized a correlation between EPC and aesthetics too (Olaussen et al., 2017).

In the context of a more extensive work focusing on cost-benefit analysis of interventions finalized to improve buildings' energy efficiency, B. Manganelli and colleagues (Manganelli et al., 2019) estimated the marginal prices associated to different EPC ratings in three different contexts by the means of categorical regressions (i.e. an approach that treats EPC as a categorical variable in the realm of an iterative regression model called the alternating least squares model); authors found that in the most valuable areas (e.g. city centre of Bari) energy efficiency plays only a secondary role in the value formation process, whilst location is of primary importance. For what concerns the value increase when shifting from a lower EPC rating to the next, authors found that the last jump (i.e. from B to A) was the one evaluated by the market as the most important.

Pooled-OLS and Instrumental Variables Hedonic Models were applied by other authors (Taltavull de La Paz et al., 2019) to the entire province of Alicante – which extends over different climate zones- instead: researchers found a partial green premium when energy-efficiency improvements increased the EPC rating from G to F (+1.8%) and from F to E (+1.1%). Additionally, different green premiums were found for properties located in different climatic areas, with intermediate zones manifesting the highest green premium. For authors, this pattern indicated the existence of a higher sensibility in regions with greater weather instability.

OLS and quantile regressions were used for instance by R. Evangelista and colleagues (Evangelista et al., 2020) to analyse a large set of sales prices referring to Portugal (years 2009-2013). Overall, authors did find a price premium for energy efficiency, which was more pronounced for apartments (13%) than for houses (5 to 6%). Additionally, authors reported that these price premiums tended to increase from 2009 to 2013. Then, conditional quantile regressions were applied to detect the impact of energy efficiency over the distribution of residential property prices: results highlighted the existence of a price premium for energy efficiency across the entire spectrum of prices; moreover, authors reported that the impact of energy efficiency seemed quite stable across the quantiles.

Quantile regression was applied also by M. Whilelmsson (Whilhelmsson, 2019) when analysing a large data set of real estate transaction prices (more than 100,000 observations) in Sweden. By a methodological perspective, the author also addressed the selection bias issue (i.e. risk that there is a different probability that observations are included in the sample under study) through the propensity score method, considering dwellings with an A-C EPC rating as "treatments" and with D-G EPC ratings as control group. Then, spatial autoregressive models were applied too. In synthesis, it was found that the price difference between the treatment group and the control group was small and not statistically significant. Additionally, the author found that the impact of high energy performance on prices was present in all housing price segments and that the percentage was almost the same for all segments. With reference to location, a higher impact was found for Northern parts of the country instead.

OLS and quantile regression have been recently experimented also by M. McCord and colleagues (McCord et al., 2020b) in the context of Belfast's real estate market. Like the work presented above (Whilelmsson, 2019), their research stands out since the study does not analyse listing prices but actual transacted prices, thus offering a perspective that best incorporate the value attributed by the demand side too. Through this approach authors found that the effects of EPC-ratings were not constant or significant across the entirety of the pricing structure, with premiums existing in the higher EPC-rated properties at the higher levels of the price distribution. The article continues stressing that the relationship between energy performance and property value is not straightforward, and that the market may value not only actual EPC scores but also EPC potential scores; in other words, *"if the current score is good, purchasers pay a little more than otherwise. If the current score is poor but potential score is good, they pay up and move on. If the current score is poor and potential score is poor, then a discount is evidenced"* (McCord et al., 2020b, p. 429). With reference to potential scores, authors advanced the existence of a "latent" attribute able to both positively affect the highest price segments of the B-rated energy-efficient properties (i.e. presence of price premium) and negatively affect the properties with the lowest ratings (i.e. presence of a "brown discount").

Latent relationships between EPC scores and real estate prices were explored by the University of Ulster (McCord et al., 2020a) also through binary logit regression models specified in conjunction with a Polytomous Universal Model; the aim of the work was to examine the likelihood of EPC ratings falling within a particular property type and the likelihood of any pricing effects. Results did not show evidence of an increased probability of a growth in sales price for units with higher EPC ratings. Overall, logit and ordinal regression-based methodologies were applied to evaluate the inter-relationships between property characteristics, EPCs and value; results seemed to suggest the presence of a complex and dynamic relationship between the nature of the property type (i.e. apartments, terrace houses, detached and semi-detached houses, etc.) and its energy efficiency and sales price.

A. Bisello and colleagues (Bisello et al., 2020) analysed the listing prices of a sample of residential properties located in Bolzano (Italy) by the means of the Hedonic Price Method, then performing spatial specifications: overall, authors found a price premium in excess of 6% moving from the worst EPC rating ("G") to the best ("A"), being equal all the other characteristics. Additionally, they detected a spillover effect exerted by retrofitted properties on nearby residential units, highlighting that this might represent an additional benefit of energy-efficiency interventions.

A spatial approach was already followed by F. Dell'Anna and colleagues (Dell'Anna et al., 2019) for the analysis of a sample of apartments located in the cities of Barcelona (Spain) and Turin (Italy); in this case, authors found that in Barcelona each step of EPC ranking allowed a + 2% in the total listing price while in Turin the calculated percentage was +6.8% instead. Then, the correction of the spatial autocorrelation allowed authors to improve the model fitting: corrected percentages were 1.88% and 6.33% respectively. Authors also concluded that while in Barcelona air conditioning and swimming pool were particularly valued by the

market, in Turin (which is characterised by a different climate zone and a cooler weather) EPC ratings resulted to have a higher importance instead.

With reference to the effects of EPCs on the real estate market of Turin, other authors (Barreca et al., 2021) have more recently found that low EPC ratings (i.e. E, F and G) significantly and negatively affected housing prices; high EPC ratings (i.e. B, A1, A2, A3 and A4) had a lower but positive influence instead. Authors performed Spatial Error Models, and they found that different spatial clusters resulted to behave as different sub-markets. Interestingly, authors also noted that, compared to previous studies (Fregonara et al, 2014; Fregonara et al., 2017), price premiums increased: in fact,

the analysis of 2011-2014 data actually highlighted that EPC labels had no impact on prices of local apartments located in old buildings (Fregonara et al., 2017).

The effects of EPC ratings on the real estate market of Turin were explored by the means of spatial econometrics by M. Bottero and colleagues (Bottero et al., 2018) too: among multiple results, authors particularly underlined that level of maintenance plays an important role in the price formation process.

M. McCord and colleagues (McCord et al., 2020) analysed the prices registered for real estate transactions in the Belfast Metropolitan Area through a variety of methods, including Geographically Weighted Regression and Spatial Lag Models. Overall, different EPC effects were detected for different property types, age of construction and location. Authors found that a capitalization effect was not always present, since high prices did not always connotate superior energy efficiency. Additionally, authors found a composite effect of EPC and heating type (gas heating), underlining that the actual impact of EPC on prices need to be evaluated carefully.

In a study focusing on Bucharest, some authors (Taltavull et al., 2017) applied a spatio-temporal auto-regressive approach and they found that energy efficiency was associated to a price premium in two (out of 5) areas of the city. The estimated green premium for the overall city was +3.5%.

Through a Spatial Error Hedonic Model, A. Chen and C. Marmolejo-Duarte (Chen and Marmolejo-Duarte, 2019) found that price premiums were associated to "A" ranked homes in 2014 and "B, C, D" ranked homes in 2016 in the Barcelona metropolitan area. Additionally, authors highlighted that "A" ranked homes were located in peripheries where new completions were developed; "B", "C" and "D" were found in more central locations in neighbourhoods of wealthy population, instead.

C. Marmolejo-Duarte and colleagues (Marmolejo-Duarte et al., 2020) applied a Geographically Weighted Regression approach to the analysis of EPC marginal prices for apartments located in the Barcelona area (Spain) and they found a premium equal to 1.7% for each EPC ranking. However, authors explained that energy efficiency overall remained one of the less important variables in the real estate pricing process. Interesting, authors reported that the premium found when analysing April 2016 data (i.e. almost three years after the inclusion of EPC ranking in real estate advertisements became mandatory in Spain) nearly doubled the premium reported for data referring to November 2014: this seems to reinforce what we stated in the Introduction, i.e. that it is likely that the appreciation of buildings' energy efficiency by the market will change coherently with regulatory frame-

works and the evolving degree of awareness concerning the vast realm of energy efficiency. Following a spatial approach, authors also found that the apartments registering the largest impact of energy-efficiency were located in peripheral areas mainly populated by medium and low-income residents. In wealthier areas, other characteristics of the apartments seemed to influence the market instead. On this point, C. Marmolejo-Duarte and A. Chen (Marmolejo-Duarte and Chen, 2019) already warned about the necessity of retrofit subsidies in order to mitigate possible negative effects generated by energy requirements on vulnerable social segments: in fact, through an OLS analysis applied to a set of 3,479 apartments located in the Barcelona area (Spain), they found that the "A" EPC rating exerted the maximum effect in the market segment characterized by poor architectural quality and located in working-class neighbourhoods, i.e. a context where only few subjects might be able to perform interventions finalized to enhance energy-efficiency.

P. Morano and colleagues (Morano et al., 2020) analysed the contribution of the energy performance component on the prices of two hundred residential properties sold in 2016-2017 in Bari (Italy) by the means of a data-driven technique employing a genetic algorithm aimed to identify the best functional expressions. More specifically, authors applied the Evolutionary Polynomial Regression approach and the model obtained pointed out that the "extreme" labels (i.e. A and G) were the ones which were able to exert the highest contribution on selling prices. Authors also noted that the properties associated to an A-label were either new or recently renovated, whereas G EPC labels were associated to properties characterized by a low level of maintenance and/or to be restructured yet.

With reference to the relationship between EPC and another interesting variable (i.e. speed of sale), E. Aydin and colleagues (Aydin et al., 2019) highlighted that, for what concerns a large sample of single-family homes in the Netherlands (i.e. 876,000 observations referring to the period 2008-2016), energy-rated homes sold faster than non-energy-rated homes. In the case of a sample of apartments located in the Helsinki metropolitan area (Fuerst et al., 2016b), it was found a slightly shorter time on market for the high-rated units and a longer period for the E-rated apartments (compared with the average energy class D). However, coefficients were statistically insignificant. A very low explanatory power of EPCs on the variable time on the market was found by E. Fregonara and colleagues (Fregonara et al., 2017) when investigating the 2011-2014 Turin's real estate market instead.

A stated preference approach was then used by some authors to investigate the willingness to pay for improving the energy efficiency of homes (Marmolejo-Duarte et al., 2020d) in Barcelona (Spain): results overall highlighted divergent sensibilities of respondents according to their demographic and socio-economic conditions, awareness of EPC scheme and environmental issues and so on.

Then, it must be mentioned that the relationships between green attributes and residential real estate prices have been studied considering not only the overall energy performance of residential units but also the presence of specific green attributes such as -for instance- photovoltaic plants installations. As an example, C. D'Alpaos and M. Bragolusi (D'Alpaos and Bragolusi, 2020) investigated the topic

through a contingent valuation approach, showing that participants were inclined to pay a premium price for solar homes.

In the context of a study with a broader aim, V. R. M. Lo Verso and colleagues (Lo Verso et al., 2014) investigated the willingness to pay an extra price for houses characterised by enhanced indoor environmental quality and by attributes allowing energy savings, instead: authors found that nearly 40% of the questionnaire participants declared to be keen on paying up to 25% more for a house with characteristics allowing energy savings; the percentage of questionnaire participants that expressed to be willing to pay the same extra price (+ 25%) for a house with enhanced indoor environmental quality amounted to 26% instead. Interestingly, authors overall underlined the rise in the market of a new sensitivity towards environmental and energy issues.

Building on these findings, it can be advanced that the conduction of studies able to capture the revealed and/or stated preferences for retrofit or retrofitted residential units (e.g. through the measurement of the willingness to pay for specific products/ interventions and/or through the analysis of transacted prices) could represent a valuable area of study, especially if investigations are carried out taking into account the socio-economic characteristics and green attitudes of the subjects involved: in fact, these studies will allow to express in monetary terms the multidimensional values associated to green interventions.

4.4 Research trends and perspectives: a synthesis

Overall, the review of the articles included in the analysis seems to highlight the presence of some trends in the most recent peer-reviewed literature. A synthesis is presented below, together with some comments for future research:

1) the spatial scale of the studies varies, and analysed samples included data at the intra-city and city level, but also at the metropolitan, regional and national level. Overall, this variety is a signal of the multiplicity of the research questions explored by authors, and future studies should be able to identify the most appropriate geographic scale in relation to the perspectives set by the research questions. In this process the availability of appropriate datasets is not irrelevant: in fact, the nature and extension of datasets can either facilitate or prevent the development of specific lines of research;

2) the type of housing solution under study is well explained by some authors, whereas in other cases the composition of the sample appears less detailed. Whereas studies focusing on Northern Europe countries have frequently explored the relationship between EPC ratings and single-family houses, recent papers on Mediterranean countries have particularly analysed apartments located in multi-family dwellings. In general terms, the future provision of details on the characteristics of the local housing stock and on the prevalent building type would enrich contextualisation and the interpretation of results;

3) with reference to the type of residential solution, some authors reported a greater effect for apartments with respect to houses (Evangelista et al., 2020), but

the relationship between the property type, its energy efficiency and prices seems overall complex and it requires further development (McCord et al., 2020a). Since single-family houses would be particularly eligible for the integration of renewable energy sources, future studies could also try to investigate the relationship possibly occurring between this specific green attribute and the appreciation manifested by the market;

4) contributions analyse the relationships between EPCs and real estate prices referring to different timeframes (i.e. length of the time span under consideration) and different years. The peculiarities of each study seem related to reasons internal to the research but in some occasions they might also be related to available datasets. In general, the reasons behind the selection of certain timeframes should be always clarified by authors and reference to the regulatory framework in force during the investigated timeframes should be always made explicit too. In fact, this would help monitor whether different energy-related policies are associated to some effects in terms of real estate prices; additionally, it would be interesting to capture the time span that is necessary for the market to acknowledge these policies and translate them into detectable price effects;

5) as an extension of the point above, it must be evidenced that in some cases (Barreca et al., 2021; Evangelista et al., 2020; Jensen et al., 2016) authors have reported that price premiums for energy-efficient residential units tended to increase through time, especially for what regard certain EPC classes (e.g. units with higher ratings). This pattern seems particularly interesting and it would be beneficial to explore whether this trend will expand and grow, also in relation to the implementation of new green policies and the possible spread of green awareness. In this framework, to perform consistent studies with a diachronic perspective, the regular retrieving of data would be recommendable. The exploration of the socio-economic and behavioural characteristics of "green-buyers", as well as the monitoring of the evolution of "green value systems" and the detection of possible "green imitative behaviours" would be interesting too. Additionally, an analysis that combines green attributes, transaction prices and possibly buyers' profiles might help better understand in monetary terms to what extent environmental benefits are valued (especially in the case that a clear economic advantage is not associated to retrofit interventions);

6) comparative studies – that observe for instance cities located in different climate zones (Dell'Anna et al., 2019), cities with a similar environmental context (Manganelli et al., 2019), but also different city-areas (Barreca et al., 2021; Taltavull et al., 2017)- have started to emerge, thus extending the research perspectives and the investigation of differences/commonalities between multiple contexts. These types of studies, in addition to enriching the general literature framework, will especially allow to better reflect on the role played by variables such as the geographical and climate zone, the building type, the maintenance level of the housing stock, the socio-economic characteristics of the neighbourhood etc. However, it must be recalled here that housing energy efficiency is calculated and categorised heterogeneously by EU Member States, and a step towards additional comparative studies would be the development of a standardised EPC rating model (Dell'Anna

et al., 2019). Making explicit the regulatory framework in force during the investigated timeframes would be essential for comparative studies analysing cities of different countries: in fact, it is known that the translation of the European Directives into national legislations does not occur simultaneously in all EU Member States. Then, it must be recalled here that, also at the country level, some differences in energy requirements (e.g. at the regional level) may exist; moreover, at the country level climate differences commanding different energy needs exist too (Chiesa and Fregonara, 2019; Fregonara et al., 2020). As a consequence, when performing comparative studies, all these peculiarities should be taken into account;

7) the analysis of listing prices (rather than transaction prices) is still frequent. Even though listing prices can be considered as a good proxy for the value of real estate assets, this suggests that the studies performed so far have probably mainly captured the value of green attributes as perceived by the sellers and/or the real estate intermediaries (supply side). This seems to indicate that, apart from research questions, elements that may greatly influence the investigation of the phenomenon are the nature and availability of data: as a consequence, further studies should try to investigate transaction prices whenever possible and, in order to reach this goal, partnerships with real estate agencies or other actors (in compliance with privacy and local legal regulations) should be encouraged. Other types of studies that have estimated the value attributed to green attributes by potential buyers (demand side) are the ones that have applied contingent evaluation instead;

8) the recent literature confirms that homogeneous effects of EPCs on real estate prices have not been detected yet. In some cases, extreme classes (i.e. A and G) tended to exert the greatest effects on prices (positively and negatively respectively), but in some occurrences a higher positive effect was progressively registered not only for A-rated units but also for units labelled with B, C or D. In other cases, a similar increase of value was registered for every jump from one class to the next. With reference to transaction prices, some authors found that the effects of EPC-ratings were not constant or significant across the entirety of the pricing structure. These results highlight a great variety of patterns, and the specificities behind these phenomena should be deepened, considering a range of different characteristics. At the same time, it must be mentioned that recent studies have also started to explore the role possibly played by single green attributes or by variables related to specific energy-related facilities (e.g. air conditioning, type of heating, etc.), thus enriching the list of intrinsic characteristics (e.g. brightness, floor, elevator, etc.) usually investigated in the real estate literature (Lo Verso et al., 2014);

9) even though the Hedonic Price Model-OLS approach still prevails, the most recent articles tended to employ methods able to answer more specific and refined research questions. For instance, recent studies aimed to explore the spatial dimension (e.g. applying spatial statistics, Geographically Weighted Regression, spatio-temporal autoregressive analysis, etc.) or the relationship between EPCs ratings and specific pricing segments (e.g. employing quantile regressions). The further development of these approaches would allow to better articulate the discourse on EPCs ratings and real estate prices, possibly identifying differentiation patterns in relation to variables such as location, type of buildings, age of con-

struction, presence of certain intrinsic characteristics of the residential unit, pricing distribution, etc. Future studies could also try to hypothesize and test cause-effect relationships between variables;

10) recent studies have identified new variables that may affect the market, such as potential EPC scores (McCord et al., 2020b), i.e. the energy efficiency level that could be obtained after retrofit. This variable appears to be of particular interest especially at this specific time, since EU Governments are providing economic incentives for retrofit, and the potential EPC scores could thus be particularly valued by potential buyers.

Moreover, some authors have underlined the necessity to investigate whether effects on prices are truly exerted by EPCs or rather by the presence of specific attributes/green attributes or even by a combination of EPC and specific technical characteristics (McCord et al., 2020b). Additionally, some authors have highlighted the problem of omitted variables possibly correlated with the energy label (Olaussen et al., 2017). These perspectives of research appear to be particularly promising, and the implementation of methods able to calculate the different effects exerted by a variety of variables and by a combination of variables could enrich the research framework and better address refined research questions.

In light of these considerations, a possible path towards the expansion of the research perspectives outlined above could be represented by the investigation of latent variables possibly affecting real estate prices. More precisely, future studies could follow approaches able to explore the relationships between latent variables, characteristics of the residential units (included EPC ratings) and real estate prices. Among available methods, an approach that seems particularly suitable and worth exploring is Structural Equation Modelling (SEM). SEM is a multivariate statistical approach that allows to study latent (i.e. not directly observable) variables, to estimate direct and indirect effects and to test hypothesized cause-effects relationships between variables. SEM capitalises on techniques such as factor analysis, path analysis and simultaneous regressions (Bollen, 1991; Corbetta, 1992; Ullman and Bentler, 2013; Wang and Wang, 2020). Mainly applied in Econometrics, social sciences and economics, SEM is an approach that has already been employed to study the real estate pricing process so far (Bravi and Fregonara, 1996; Freeman and Zhao, 2019; Liu and Wu, 2009; Manganelli, 2001; Manganelli and Morano, 2001), but the integration of green attributes and energy efficiency among analysed variables has not been systematically explored yet. As a consequence, testing the potentialities of SEM with reference to the topic mentioned above could represent an enrichment to this field of research, both in terms of possible results and methods adopted.

5. Conclusions

The present article has outlined that, despite homogeneous effects of energy efficiency levels on real estate prices have not been detected, some trends in the most recent peer-reviewed literature focusing on European contexts can be iden-

tified. Overall, they mainly regard the refinement of the research questions performed and the research methods consequently adopted, with a special attention towards the analysis of the spatial component and the identification of different effects on various housing segments and pricing distributions.

If studies on the effects of EPCs ratings have been performed since the establishment of the first EPBD, the relevance of the topic has progressively assumed increasing importance, and the statements presented by the European Commission in the document *"A Renovation Wave for Europe- greening our buildings, creating jobs, improving lives"* (European Commission, 2020) induce to advance that in the near future further studies will be needed, especially to monitor the effectiveness of EU and national policies, evaluate concurrent effects (e.g. on real estate values, environmental indicators, etc.) and then take further action.

Even though EPBDs have provided a common framework to the European context so far, Member States have nonetheless implemented energy efficiency guidelines at a different pace and in different ways, making the comparison of results hardly straightforward. The revision of the EPCs and the creation of accessible databases prospected by the *Renovation Wave* will probably facilitate the monitoring of the energy efficiency of European buildings and the provision of useful and usable data instead.

Since the *Renovation Wave* conceives retrofit not only as a set of interventions finalised to reach environmental goals and decarbonisation but also as an economic leverage able to create green jobs, in future studies it will be interesting to analyse whether retrofit will have an economic reflection also on another facet of the exchange economy, namely real estate prices. In this context, an area of research may regard for instance the identification of green premiums and brown discounts associated to specific EPC ratings, building types and their location. Considering location not only in terms of geographic and climatic position but also as an element to which socio-economic variables are ascribed would allow to extend the discourse on a socio-economic level too. In these reflections, considerations should be particularly made on the effects that policies and economic incentives have on the most fragile segments of the population, which seem to have been affected by brown discounts so far.

The evolution and progressive refinement of research questions have led scholars to apply different methods, ranging from the well-established Hedonic Price Model to spatial analyses and different regression approaches. Given that effects on real estate prices might be exerted not only by EPCs as such but also by a combination of EPC and other characteristics, future studies could experiment the application of Structural Equation Modelling, i.e. a statistical approach that allows to estimate direct and indirect effects, as well as to study latent (i.e. not directly observable) variables and cause-effects relationships.

Concerning future research, the perspective is threefold. Firstly, a further review work will be done considering the cyclical variability of prices and the market dynamics which can influence not only the models results but also the selection of the appropriate model itself. Specifically, the availability of significant data samples, in view of the number of transactions, could allow a comparative explo-

ration of the models implied and eventually to increase the number of contributions also from further Member States involved in the academic research. Secondly, speaking about the methodological exploration, a further research work will be done exploring the potentialities of SEM, which emerged – as said before – as a particularly promising procedure. Given its peculiarities, the application of this approach could then also be extended to a macro-level, to investigate possible effects induced by energy-related policies. On the basis of the literature described in previous paragraphs, an "Energetic Quality" latent variable (encompassing comfort, as well as savings and environmental benefits) could be hypothesized. By the means of SEM, future studies could try to investigate this variable through measurable indicators, as well as to detect the effects exerted by identified variables on the real estate pricing process.

Thirdly, it must be considered that the present work has assumed the building scale perspective and, thus, a wider exploration is necessary considering that the issues explored, in many cases, involve the district-territorial scale, and, implicitly, the urban governance and policies which are strictly related to the energy-environmental sustainability.

The urban metabolism has to be adaptive to today's challenges – i.e. environment, climate change, economy –, and possible solutions for the reuse/retrofit of existing structures and infrastructures need to be adaptive to today and future changes too. The design of the solutions will include the urban context, considering private/public spaces in a sustainable perspective, from the neighbourhood scale to the building scale. The balance between architecture and environment will be the core for the definition of design strategies and related technologies, including buildings' green attributes. In this framework, their impact on pricing processes and real estate market dynamics will need to be detected with the appropriate models.

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