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# EPC Green Premium in Two Different European Climate Zones: A Comparative Study between Barcelona and Turin

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Received: 4 September 2019; Accepted: 5 October 2019; Published: 11 October 2019

**Abstract:** Energy performance certificates (EPCs) are important tools aimed at improving buildings' energy performance. They play a central role in the context of the Energy Performance of Buildings Directive (EPBD) which asks member states (MS) to take the necessary measures to establish a complete certification system. In this study, an application of the hedonic price method (HPM) assessing the effect of energy labels derived from the EPC on real estate market value is presented. The estimation methodology was applied to two European cities characterized by different climate conditions. The analysis was based on two datasets of listing prices referring to multi-family residential markets in Turin (Italy) and Barcelona (Spain). Four models for each dataset were applied to capture the marginal price of green attributes, but also to control for the spatial autocorrelation among values. The findings showed how the EPC has been applied in the two countries and how it has influenced the real estate market. Turin's buyers pay more attention to the EPC label, while in Barcelona, they value much more single characteristics, such as air conditioning and a swimming pool, considered popular attributes among contemporary buildings in this climate zone. From the results, it is possible to deduce that the implementation of the EPC schemes is still irregular in EU countries and must be strengthened through a standardized rating model.

**Keywords:** energy performance certificate; green label; climate zones; hedonic prices method; spatial econometric models; spatial autoregressive model; spatial error model

## 1. Introduction

In 2002, the European Union (EU) introduced the Energy Performance of Buildings Directive (EPBD) in order to promote energy efficiency in the building sector [1]. The reduction of energy consumption and the use of renewable resources represent important measures aimed to reduce EU energy dependency and pollutant emissions. The first recast of EPBD, Directive 2010/31/EU (EPBD 2010/31/EU), promotes the improvement of buildings' energy performance within the EU and introduces a new standard for new buildings built by 2020: the nearly-zero energy building (nZEB or NZEB) [2]. The EU asked member states (MS) to draw up national guidelines for increasing the numbers of nZEB projects, develop policies, and fix targets to increase the quality of the buildings and fight against climate change. To facilitate the application by MS and guarantee flexibility, the Directive gives only a qualitative definition of nZEBs [3]. In 2010, the EU introduced the Energy

Performance Certificate (EPC) as a synthetic indicator that expresses energy performance to promote the improvement of buildings' performances thanks to the information provided to prospective owners and tenants about energy consumption. The EPC is a mandatory assessment of new buildings for construction companies and, at the time, when selling or renting for the owners. However, a certain level of flexibility in reaching these goals is tolerated. The Directive does not prescribe a uniform approach for its implementation [4]. In 2015, during the 21st Conference of the Parties of the UNFCCC (United Nations Framework Convention on Climate Change) in Paris (COP21), new visions aimed at decarbonizing the building sector by 2050 were set and accepted by the latest European Directive [5]. With the Directive 2018/844/EU, the European Union shifted attention toward real estate by proposing to MS a census of building stock, both public and private, and a program to reach the main goals [6].

The existing building stock represents a potential means to achieve by 2050 the environmental targets set by the EU. Indeed, 67% of the buildings in Europe were built before 1980, and only a small percentage of them (0.4–1.2%) are retrofitted. As MS have adopted the EPC according to their national and regional rules and despite being a request from the EU, many of them have not set this Directive as mandatory for owners when selling or renting a building, for example as in the Czech Republic and the Netherlands. With this perspective, it is interesting to understand the effects of the Directive in the different EU countries and whether the EPC has met its expectations as a tool to promote energy efficiency. Several studies share a common methodology based on hedonic prices to investigate the effects of EPC on real estate values, using both listing data and transaction prices. In Europe, many studies have been developed in northern countries to verify the effect of EPC on market prices. Most of the studies were carried out in the Netherlands [7,8], United Kingdom (UK) [9–11], Austria [12], Ireland [12], Romania [13], Finland [14], Sweden [15,16], Norway [17], and Germany [18,19]. Whereas countries located in the Mediterranean area have been little studied in the academic literature [20–22].

Another significant issue that has been little studied in real estate market investigation is the difference in consumers' appreciation for the characteristics of housing in different climate zones [22]. In this context, it is interesting to understand how climate variables influence consumers' choices and if some typical characteristics of local construction are appreciated more than green ones. More specifically, this study aims to compare the effects of the EPC rating in two European cities located in the Mediterranean climate zone: Barcelona and Turin [23]. The present paper tries to contribute to the literature about the effects of EPC on real estate values in Southern European countries as they are scarcely considered. The cities of Barcelona and Turin are characterized by a dynamic property market although they are not national capitals. They are two compact cities with a very similar building stock. Barcelona and Turin are cities with many centuries of urban history. The Roman nucleus, the medieval, Renaissance, and Baroque perimeter and modern enlargement are clearly identifiable in the urban fabrics of both cities. The Renaissance and Baroque densifications are very similar. Since the seventeenth century, Turin adopted an urban chessboard grid for urban development outside the Roman walls. As in many other Mediterranean cities, the grid model was proposed in 1855 by Ildefonso Cerdá for Barcelona's expansion. This urban sprawl design was able to establish orderly and decentralized growth for the development of contemporary cities according to a very compact model [24]. The similarities in urban development and regeneration policies have also been found in recent years. Indeed, Barcelona and Turin have exploited major events such as the Olympics Games to renew and re-use abandoned industrial areas included in the urban fabric, in 1992 and 2006, respectively [25]. Furthermore, the most common type of building in the residential market is the apartment, and most of the multi-family homes, around 60%, were rebuilt in the second post-war period in both cities [26]. Despite being in the Mediterranean climate zone, Turin and Barcelona are characterized by two different microclimates; Barcelona with a mild and relatively rainy winter and a hot and dry summer; Turin with cold and wet winter and a hot and muggy summer. Moreover, Turin needs much more energy for heating, while, in Barcelona, the heating system is very often not present. On the other hand, the cooling system is essential in the Spanish city, especially in the warmer months.

In contrast to some extra-European studies [27–30], in Europe, few scholars have studied the effect of location on market values in green labels investigation. The importance of space in determining real estate values is widely recognized. In this perspective, Dubin [31] introduced the spatial effects in the hedonic model based on the autocorrelation of the error term in the hedonic regression. The error term can include omitted variables that are spatially clustered, such as building typology, age of construction, and neighborhoods' quality. Another issue is instead linked to the adjacency effect due to the nature of the real estate market [32]. LeSage and Pace defined this influence as a spillover effect among the prices of neighboring properties [33,34]. The EPC is a synthetic indicator of intrinsic variables related to a building's components (such as the opaque and transparent envelope, and energy system) that can vary spatially because they are linked to the temporal development of the city. In this context, the introduction of spatial autocorrelation places variables linked to the homogeneous localization of building typology under control since the omission of such spatial correlations may bias the estimates. To consider spatial effects, the traditional Hedonic Prices Model (HPM) proposed by Rosen [35] was implemented with a spatial auto regressive model (SAR) and a spatial error model (SEM) [36,37].

The paper is organized into five sections. After the Introduction, Section 2 offers a literature review of HPM applications in Europe investigating the impact of EPC on real estate prices. Moreover, it explains the main difference in the adoption of the EPC in the EU and clarifies the motivation of the study. Section 3 describes the datasets and the variables included in estimating. The application of the ordinary least squares (OLS), SAR, and SEM models is shown in Section 4. The main conclusions are discussed and summarized in Section 5.

## 2. Theoretical Issues

### *2.1. Investigating the EPC Impacts through HPMs*

Since the EPC rating is, together with the EPI (energy performance index), one piece of information contained in property advertisements describing a building's energy performance, and whose publication on the announcement is mandatory by law, many studies have investigated whether this information influences consumer choices.

A review of the literature on the application of HPM for the EPC valuation in European countries have been performed [38]. The cases analyzed refer to residential and commercial property markets [15,39,40]. One of the first European studies investigating the effect of the EPC on property prices dates back to 2012 and it was proposed by Kok and Jennen [7] in the Netherlands. Following Rosen's theory and methodology, the study investigated the effect of the EPC on 1100 rental transactions of office buildings. The results showed that non-green buildings were 6.5% lower compared to those in the upper EPC rankings. Brounen and Kok [8] highlighted how the information on the energy label is appreciated at the time of the sale in terms of an increase in price and how a labelled property is sold first in the Dutch residential market. Cajias and Piazolo [19] applied the hedonic prices theory to test the relationship between rentals and sales with the EPC ranking in Germany. In the case of rentals, buildings ranked as B, C, and D were rented between 0.47 €/$m^2$ and 0.74 €/$m^2$ more than G-ranked buildings. The same result was confirmed in the case of sales, where buildings below the optimal range of 200 kWh/$m^2$y recorded, on average, a 32.8% increase in real estate value. Högberg [41] demonstrated how the EPC influences the selling prices of single-family homes in Sweden using a dataset of 1073 observations. The results indicate that Swedish buyers consider the energy label to be important when buying a property, as witnessed by growth in prices as the energy class increases.

In 2013, the EC (Directorate-General for Energy) published a report including various applications in different European countries to verify the impact of the energy label on the properties values [12]. The countries involved were Austria, Belgium (Flanders, Wallonia), Brussels, France (Marseille, Lille), Ireland, and England (Oxford). The impact of the EPC rankings on the real estate price depended very much on how long it was mandatory. In the cases where the obligation of the EPC was set for some time, a certain effect on property values did exist, while in the countries where the rule application was recent or ineffective, the information on energy performance did not have a significant influence at the time of purchase. Despite this, in almost all the studied countries there was an increase in the real estate value according to the energy ranking, except for the case of Oxford for the rental market, possibly due to the poor control of architectural quality and location in the HPM. Hyland et al. [42] investigated the effects of energy efficiency in residential properties by analyzing sales and rentals in Ireland. The authors show how energy efficiency has a positive effect on both. An A-ranked property received a selling price premium of 9% and a rental price premium of just under 2% compared to D-ranked ones. Moreover, the authors tested the EPC effects across time. They found that the impact on property price for dropping each level on the EPC scale was larger when selling conditions were worse. According to authors' opinion, due to the lack of funds to conduct renovations on properties, buyers prefer properties which will not require further investment on retrofitting. A set of studies was developed in the UK by Fuerst et al. [14,43] to investigate the effect of energy performance on real estate sales prices. The authors found a positive association between sales and energy performance rankings. Compared to apartments ranked as D, buildings ranked as A and B were sold at a premium of 5%, and those ranked as C for a premium of 1.8%. While, dwellings ranked as F, E, and G were sold for approximately 1–7% less [43].

As previously stated, the impact of energy performance on real estate prices has been poorly studied in Southern European countries. In Italy, Fregonara et al. [44] and Bottero et al. [45] employed hedonic models to analyze EPC impacts on residential real estate prices in Turin. A premium on transaction prices of Italian properties with high-efficiency rankings was found. The findings suggest that the Italian real estate market is appreciating green buildings compared to others. In 2014, Ramos et al. [20] propose a study on residential properties in Portugal. This research confirmed the theory of most previously developed studies, showing that properties with EPCs ranked as A, B or C were sold at a 5.9% higher price per square meter than those with an EPC equal to D. On the contrary, apartments with low energy rankings (E, F or G) were sold at 4% less than D-ranked properties. In 2019, Evangelista et al. [46] proposed a study in Portugal on residential properties confirming the results of Ramos et al. [20], although the values of the coefficients identified were greater. New and existing apartments ranked A and B received a sales price premium of 13.1% and 12.5%, compared with less efficient properties. This is most likely due to the datasets used; Ramos, indeed, employed listing prices and a smaller sample. De Ayala et al. [21] applied the hedonic prices method in Spain in the residential market using the survey results on housing characteristics and non-experts' opinion values. In detail, they investigated the premium price of dwellings in A, B, C, and D energy rankings. The premium price ranged between 5.4% and 9.8% compared to the less efficient ones. Also in that country, a pioneer study based on actual selling prices was conducted by Marmolejo [47], who found a negligible impact on prices in Barcelona, as sellers were unable to compensate for the costs of upgrading to energy efficient building technologies. However, in a longitudinal study, Marmolejo and Chen [48] found, using a spatial HPM, a significant increase in the EPC rankings' impact on housing prices.

Marmolejo and Chen [49] investigated how the impact of energy rankings differs in various housing segments in Barcelona. The findings suggest that energy ratings seem not to influence the prices of more recent apartments. On the contrary, in the case of other properties, the EPC produces a considerable impact that strongly influences price variation. Taltavull et al. [22] followed Rosen's method to assess the green premium in the province of Alicante. The study is very interesting for the aim of the present work because it investigates the EPC in relation to various climate zones. The results show differences in green premiums among areas, recording a sensibility of residential listing prices to the energy efficiency equal to one-third lower in hotter regions. Along the same lines is the work of Marmolejo and Chen [50] applied to the Barcelona, Valence, and Alicante metropolitan areas. They found that the impact was larger when highly efficient homes were scarce in local property markets.

However, other studies have shown that there was no positive relationship between the energy class and real estate prices. In Norway, Olaussen et al. [17] highlighted that energy efficiency attributes can incorrectly absorb the impact produced on property values by other ignored explicative variables, such as those related to the construction quality. It must be recalled that the EPC is a proxy variable that brings with itself the effects of other omitted attributes. Moreover, the latter produce a spurious correlation between characteristics if they are introduced at the same time in the model. It is necessary to keep in mind that in Reference [25], a second hedonic model including the characteristics of the apartments found that the EPC had no impact on prices. Finally, Cerin et al. [16] analyzed 67,559 transactions in the Swedish private real estate market between 2009 and 2010. The authors found a negative relationship between prices and energy label, and they believe that this effect was due to the lack of reference value in the EPC classification. Besides, the results presented by Cerin et al. are not confirmed by Högberg [41] who found a positive influence on energy performance improvements on sales prices in those same years in Stockholm.

As a result of this review, it is possible to confirm that most of the literature consulted suggests that a consumers' willingness to pay for a buildings' green characteristics does exist. Few studies have shown that the effects of the EPC are minor or even null. One of the limitations of the meta-analysis is not being able to verify the input data used to do the study, but it is possible to refer only to the results presented. Starting from the general economic equation theory, HPM should guarantee a high level of completeness. However, the sampling problem and the individuals' reception trouble remain, limiting the results comparability. In the EPC investigation studies, consumers' choices regarding the energy performance of buildings vary depending on the building stock, economic factors, time, location, and, not least, on the variation of climate zones [22]. With these perspectives, this study aimed to investigate first and foremost consumers' preferences when buying a property in two cities located in different climate zones. Secondly, this paper intended to implement academic literature in the study of the spatial autocorrelation of prices. This is a novelty in relation to most of the past EPC-based published papers.

### *2.2. EPC Application in European Countries*

Based on the data provided by the EU Building Stock Observatory [51], which are updated to 2013 for all MS, most of the European-built area is made up of residential buildings. The proportion between private and public buildings varies significantly in European countries. The European average for residential buildings is about 74%. In most EU countries, half of the residential buildings were built before 1970, earlier than the entry into force of the first regulations on energy performance. In detail, in Spain, having as a reference 2014, 12.84% of the buildings were built before 1945, 18.62% between 45 and 69, 17.41% between 70 and 79, 13.07% between 80 and 89, 14.27% between 90 and 99, 17.29% between 2000 and 2009, and 6.51% of buildings were built after 2010. As for Italy, 19.8% of residential buildings were built before 1945, 31.31% (the highest share) between 1945 and 1969, 17.57% between 1970 and 1979, 12.74% between 1980 and 1989, 7.74% among 1990 and 1999, 7.88% between 2000 and 2010, and 2.95% after 2010. In practice, in Italy, about 51% of residential buildings were built before 1970. Despite Spain having a significant share of new homes (built after 2000), only 0.03% were built according to nZEB. On the other hand, Italy registers a 15.86% share of nZEB in the field of new construction [52]. With a view to the European energy transition, the European Commission considers the role of the building sector to be central to exploiting its enormous potential for energy savings and greater efficiency of the building stock [53]. According to the European Commission, with the current refurbishment rate in Europe, equal on average to 1%, it would take a century or so to decarbonize the building stock. Spain records an annual restructuring rate of less than 0.1%, registering the lowest rate for all European countries.

As said above, in 2002, the introduction of the EPBD required EU Member States to develop and implement the Energy Performance Certificate (EPC) scheme. The EPBD application was different in each of the MS, as stated by Buildings Performance Institute Europe (BPIE) documents [4,54]. There are some countries where the energy label is mandatory in order to sell/purchase a home or an office (e.g., Italy, Spain) and others where it is not (e.g., the Czech Republic, the Netherland, etc.) [55]. In some countries, the EPC is based on a certain rating, in others on a different one. Most European countries have chosen an energy classification system based on seven A–G ranks. In recent years, changes have led some countries to create subclasses, i.e., A, A+. Austria, Ireland, and Portugal, for example, foresee a further subdivision of the main energy labels that allow to show improvements that otherwise would not be evident [56]. Not all MS use non-renewable primary energy (kWh/m$^2$y) as an indicator to build reference levels of the rating scale. Some countries have decided not to use any indicator for energy performance, such as Hungary and Denmark. Ireland, to provide an energy consume indicator, requires the indication of the environmental performance measured in $CO_2$ emissions. A different degree of compliance with CEN (European Committee for Standardization) standards is registered in several European countries. In some MS, compliance has failed to reach the desired levels in terms of scope and application, while in others it is only partial. Many countries had already adopted an energy certification system or had, in any case, gained experience in this sector. Another reason stems from the complexity of the CEN standards. While in Italy the EPC is fully compliant with CEN standards and produces reproducible and comparable results, in Spain the evaluation system is totally non-compliant.

In Italy, the Law Decree (DL) No 192/2005 "Implementation of EPBD concerning the energy performance of buildings", amended and integrated by DL No 311/2006 and DL 115/2008, introduced EPCs. From 1 July 2009, the obligation to certify the EPC is for all properties. In Italy, the DL No 63 of 2013, amended by law No 90 of 2013, which implemented Directive 2010/31/EU, introduced the APE (Attestato di Prestazione Energetica) in place of the EPC, as the document that certifies the energy performance of a building through the use of specific indicators and provides recommendations for improving energy efficiency [57]. The APE must be attached to sales contracts, property transfer deeds for free or new leases, otherwise the contracts will be void. The Ministerial Decree of 26 June 2015 of the Ministry of Economic Development (Ministro dello Sviluppo Economico), containing the "National guidelines for the energy certification of buildings", has introduced a methodology of calculation the same throughout the national territory and a new single APE for all Italian regions.

The EPBD was implemented in Spain by the Royal Decree (RD) approving the "Technical Code of Buildings (CTE)", approved by the Council of Ministers on the 17 March 2006. In 2007, a basic procedure to calculate the EPC of new and public use buildings was approved by the Council of Ministers [58]. The 2010 EBPD recast was implemented by the RD 235/2013 that made it mandatory to include, as of 1 June 2013, the EPC information in most of the property advertisements addressed to the selling and rental markets. Regional governments are responsible for officially issuing the EPC after a certified professional makes the certification using a national wide methodology. The calculating methods are defined nationally. Regional governments are also responsible for keeping a regional public register that contains the results of the EPC issued in the regions.

As for existing buildings, as in most countries, in Italy just over one-third of all certified properties are ranked as D or higher (A, B, C). The share of buildings with the lowest energy class in 2014 was 84% for residential and 83.6% for non-residential properties as shared by European building stock observatory [51]. As for Italy, in the residential sector, only 1.6% of the certifications are labelled A and 5.1% labelled B, while 8.8% are labelled C, 11.2% labelled D, and 73.3% of labels are below D. In the non-residential sector, on the other hand, in Italy, 1.4% of certifications are labelled A, 4.1% have the label B, 10.9% are labelled C, 14.6% are labelled D, and 69% are labelled above D. In Spain the situation is slightly different in that less than 20% of existing residential buildings are in the rank D or higher. In 2014, only approximately 4.5% of existing buildings were ranked above D: A (0.24%), B (0.70%), and C (3.55%).

From an initial analysis, it turns out that the energy certification, despite being issued from above as a mandatory tool, in terms of implementation and scope of the application, is being adopted differently in the MS. At present, there is no common framework of standards for the provision of certification and a direct comparison of the impacts on the various MS is difficult to do. Italy and Spain have two similar evaluation systems but, in the latter, the EPC ranking system refers to a national plan, despite being under regional jurisdiction.

### *2.3. Location and Climate Issues*

Other differences among the MS are due to geographical location and construction characteristics determining how sellers and buyers perceive the real estate value of buildings' energy performances. To meet heating and cooling needs, the thermal performance of a building and the total energy consumption are strongly influenced by the climate zone and the surrounding environment. In turn, the selection of technologies, materials, and construction techniques are also influenced by the surrounding conditions, including climate, environment, type of building, and its use in order to guarantee energy efficiency and lower energy demand [59].

Internationally, the most widely used general climate classification is the Köppen–Geiger system developed by Wladimir Köppen around 1900 and subsequently revised until its definitive edition in 1936. In Europe, there are different climate regions, where in the cities of north-eastern Europe, such as Moscow, St. Petersburg, Berlin, Kyiv, and Minsk, the climate is characterized by harsh winters and lukewarm summers. The temperate oceanic climate is typical of cities in north-eastern Europe, such as London, Paris, and Amsterdam. In southern Europe, the most widespread climate is the Mediterranean one, with hot or moderately hot summers, such as cities as Madrid or Rome. Actually, the current and sudden climate change makes classification much more difficult.

From a geographical point of view, Barcelona and Turin are located within the Mediterranean climate zone differentiated by climate sub-category (Figure 1). Barcelona is located in Csa Köppen Climate Classification (C = warm temperature, s = summer dry, a = hot summer) with mild winters and hot summers [60]. In summer, there is much less rain than in winter. The average annual temperature in Barcelona is 16.5 °C. The average temperature of July, the hottest month of the year, is 24.1 °C. In January, the average temperature is 9.8 °C. The Köppen Climate Classification puts Turin into the Marine West Coast Climate, Cfa (C = warm temperature, f = fully humid, a = hot summer) [61]. According to this classification, the climate in Turin is warm and temperate. There is significant rainfall during the year, even in the driest month. The average temperature is 12.6 °C. The average temperature of July, the hottest month of the year, is 23.6 °C. The average temperature in January is 1.4 °C (the lowest temperature during the year).

Another method to provide information on climate conditions is the degree day for heating and cooling. The days in heating degrees days (HDDs) express the heat requirement for a specific period of time taking into account the external temperature and the room temperature, the latter set to guarantee a certain level of comfort. The higher the HDD value, the greater the need to keep the heating system on. Generally, to calculate the days of heating grades in European cities, the meteorological data were taken from METEONORM and calculated in days of heating degrees using the methodology applied by EUROSTAT. The inverse reasoning was developed for the calculation of cooling degrees days (CDDs) from ASHRAE. The two methodologies allow the use of a common and comparable basis for the evaluation of HDDs and CDDs [59]. In 2003, the value for the HDDs was, for the city of Turin, 2617, and the CDDs, 361. In Barcelona, the values for HDDs and CDDs were 1156 and 516, respectively. The difference in HDDs between the two cities indicates a wide range of climate conditions which can cause significant differences in energy required for heating buildings. This could be translated into a greater appreciation of green and energy-efficient buildings for Turin. On the other hand, the CDD for Barcelona is much higher than in Turin, and the presence of air conditioning systems are expected to be much more appreciated. It should be noted that climate change may have partially changed this relationship.

Two more coherent systems were created to define comparable climate zones in Europe from the Ecoheatcool project [62,63]. It must be remembered that the HDD and CDD system refers to national regulations to define the set-point temperature indicating optimal comfort conditions. Eighty European cities were used to define the European heating index (EHI) and the European cooling index (ECI). The goal was to create an index explaining the demand for environmental heating expected at uniform cost and indoor temperature. The EHI and ECI are normalized, and 100 is equal to an average European condition, while the need for heating and cooling should be proportional to these indexes. Based on the maps in Figure 1, it is possible to argue that Turin has 20% more heating needs than Barcelona, while the cooling needs are almost similar for both cities.

There is an infinite variety of climate conditions that can influence a building's energy performance. In short, it is possible to highlight substantial differences among the two cases analyzed in this study, which, in turn, can explain consumers' preferences and the local real estate market.

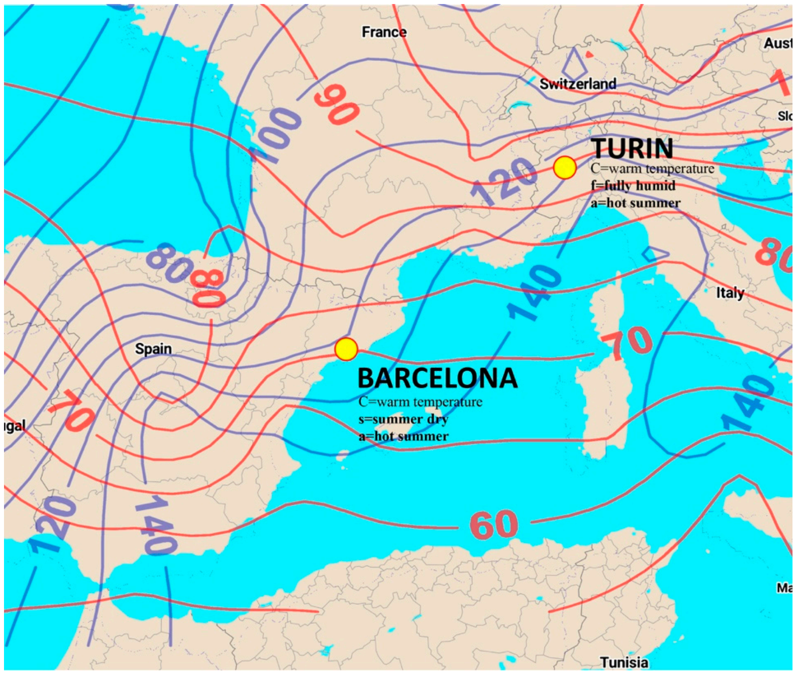


**Figure 1.** European heating index (EHI) in red lines and the European cooling index (ECI) in blue lines (source: authors' elaboration from References [62,63]).

## 3. Empirical Model

### *3.1. Hedonic Prices Method Theory*

The HPM assumes that economic assets can be seen as aggregates of different characteristics. According to this approach, real estate is like a set of attributes, able to bring benefits to the consumer, all part of the hedonic prices function (Equation (1)), so that:

$$P = f\,(x_1, x_2, \ldots x_n) \tag{1}$$

where P is the market price and $x_1$, $x_2$, and $x_n$ are the structural, locational, and environmental characteristics related to the property. To measure the relationship between the selling price and the different properties, the regression technique is employed. The multi-regression model explains the variability of a dependent variable (y) in function of the independent ones ($x_1$, $x_2$, … $x_n$). If the model is linear, the form of the function is simple as follows Equation (2):

$$y = b_0 + b_1x_1 + b_2x_2 + \ldots + b_nx_n \tag{2}$$

where $b_0$ represents the constant term and $b_1$ the coefficient of the variable $x_1$ which expresses the slope of the line [35]. The OLS method allows the estimation of the unknown parameters. The calculation provides the equation with the minimum value of the sum of squares of the deviations between observed values and estimated values of y. The linear model is often criticized for two reasons: the choice of the functional form as well as the presence of spatial autocorrelation and spatial adjacency effects.

Regarding the first issue, many scholars highlight the non-linear distribution of the relationship between price and explanatory variables [64]. Generally, to solve this problem, non-linear models are adopted, sometimes by taking the logarithms of the dependent or independent variables, or by applying a multiplicative exponential model. Accordingly, the hedonic regression equation can take the linear, semi-logarithmic (semi-log) or logarithmic (log-log) forms.

Regarding the second issue, the importance of location in determining real estate values is universally recognized. The introduction of spatial effects in HPM started from reasoning about the autocorrelation of the error term in hedonic regression [31]. In this case, the neighborhood characteristics that cannot be captured by the analyst are considered responsible for causing biased estimates. Another topic is instead related to the adjacency effect, due to the nature of the real estate market [32]. As a matter of fact, in a segmented and not perfectly competitive market, where information about prices and quantity is poor, buyers consult listing prices of nearby properties prior to making an offer. Similarly, sellers and agents use listing prices to determine a property quotation.

Considering the evolution of HPM and the starting-point of the research, i.e., testing the differences in two climate zones of the EPC's impact on real estate values, and the relevance of the local conditions (climate and structural), the application of the SEM and SAR models are considered in order to take under control the error component. Since the spatial autocorrelation implies that the price of a property is explained, not only by structural attributes, but also by the price of neighboring values or by locational characteristics [31,36,64], the introduction of spatial coordinates in the model allows to correct the spatial dependence of the error term. In this direction, the spatial correlation in the dependent variable was analyzed through SAR according to the Equation (3):

$$y = b_0 + \varrho W + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n + e \tag{3}$$

$$e = \lambda W e + u$$

where $\varrho W$ is the weighted average price of neighboring properties, and the parameters $\varrho$ and $\lambda$ are the autocorrelation coefficients [65].

Conversely, whit spatial dependence was for accounted by the error term, SEM was employed; the regression Equation (4) is:

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n + e \tag{4}$$

$$e = \lambda W e + u$$

where W is the spatial weights matrix, $\lambda$ the spatial error coefficient, and u the uncorrelated error term. Due to the simultaneity, SAR and SEM were estimated by the maximum likelihood estimator (MLE) algorithm [65].

### *3.2. Databases and Estimation Approach*

The present study follows a multi-step methodology. First of all, the data containing prices and characteristics of the property were collected from ads coming from the main Italian and Spanish real estate websites focusing on the two cities of Barcelona and Turin. In Barcelona, the information came from Habitaclia, a website collecting data from many agencies and individual owners. The Turin dataset came from a collaboration of the authors with immobiliare.it, the largest Italian website where real estate ads are collected, for the most part, from agencies. The period taken into consideration refers to the years from 2014 to 2018. Data collection mainly concerned the multi-family building type for both case studies which, in turn, is the predominant dwelling typology in both cities. The second step was the definition of the explanatory variables, paying great attention to the availability of the energy performance certificate. In the European Union, it is mandatory to include the energy label at the time of advertising regardless of whether the property will be sold or rented. In Spain and almost all Italian regions, this obligation is associated with penalties for those who do not provide information on the EPC. While almost all the Turin real estate ads had EPC information, in Barcelona, only 15 and 17% had ads for the years 2014 and 2016, respectively. This problem has led to the elimination of many observations.

Once all the valid observations were collected, further tests were carried out to identify the collinear variables and the possible outliers responsible for biases estimators. After deleting incomplete records, missing data, and outliers, the final datasets consisted of 3224 transactions for Barcelona and 15,288 for Turin. Table 1 shows the independent variables taken into consideration in the model, as well as the dependent ones.

**Table 1.** Descriptive statistics of variables.

| | | Barcelona (3,224 Observations) | | | | | Turin (15,288 Observations) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variables** | **Measure** | **Min** | **Max** | **Mean** | **SD** | **Source** | **Min** | **Max** | **Mean** | **SD** | **Source** |
| *Apartments characteristics* | | | | | | | | | | | |
| Total listing price [a] (€) | Scale | 34,000 | 3,500,000 | 371,835 | 336,820 | f | 90,000 | 3,600,000 | 186,672 | 17,506 | h |
| Floor area ($m^2$) | Scale | 20 | 600 | 99.99 | 54.59 | f | 10 | 790 | 91.48 | 46.88 | h |
| Dwelling's level | Scale | 0 | 24 | 2.64 | 2.49 | f | 0 | 15 | 2.88 | 2.14 | h |
| New/retrofitted [b] | Nominal | 0 | 1 | 0.18 | 0.390 | f | 0 | 1 | 0.51 | 0.500 | h |
| Air conditioning [b] | Nominal | 0 | 1 | 0.52 | 0.49 | f | | | | | |
| EPC [c] | Ordinal | 1 | 7 | 2.88 | 1.33 | f | 1 | 7 | 3.13 | 1.68 | h |
| Year [d] | Ordinal | 1 | 3 | 2.26 | 0.964 | f | 1 | 5 | 3.54 | 0.918 | h |
| *Buildings characteristics* | | | | | | | | | | | |
| Swimming pool [b] | Nominal | 0 | 1 | 0.058 | 0.235 | f | | | | | |
| Lift [b] | Nominal | 0 | 1 | 0.752 | 0.431 | f | 0 | 1 | 0.73 | 0.44 | h |
| *Accessibility indicators* | | | | | | | | | | | |
| Metro station (m) [c] | Scale | 4.59 | 1695 | 289.96 | 155.56 | g | 33.24 | 10,386 | 2552.49 | 1913.13 | g |
| Highway ramp (m) [c] | Scale | 1.01 | 2899 | 1214.26 | 737.78 | g | 120.47 | 11,796 | 5130.37 | 1954.12 | g |
| Urban parks (m) [c] | Scale | 0 | 2345 | 139.59 | 126.11 | g | 0 | 4211 | 1156.33 | 750.34 | g |
| Sea coast (m) [c] | Scale | 20.14 | 9033 | 3175.58 | 1621.50 | g | | | | | |

[a] dependent variable
[b] 1 if Yes, 0 if otherwise
[c] Energy Performance Certificate (A = 7; B = 6; C = 5; D = 4; E = 3; F = 2; G = 1)
[d] Advertising year (2014 = 1;…2018 = 5)
[e] Euclidean distance from nearest point
[f] www.habitaclia.com
[g] Distance calculated through Quantum GIS (QGIS 2.18)
[h] www.immobiliare.it

The "air conditioning" variable was not introduced in the Turin dataset since these conditioning systems are not common in the residential sector. The "swimming pool" variable was not included in the Turin dataset because it is a feature only for single-family homes in Italy.

The most important variables refer to the structural characteristics of the apartment (surface, floor, maintenance status, presence of air conditioning, energy class, year of announcement). Since in the real estate announcements the year of construction of the property is not included, we tried to correct for the lack of this information by entering the variable describing the new or retrofitted conservation status of the apartment. Furthermore, some of the attributes located at the building where the apartment is located were considered, for example, if there is a swimming pool or a lift. Among the locational variables, proximity to main urban infrastructures or amenities was taken into account (e.g., the nearest metro stations, the highway exit, the city's main urban parks, the distance from the coast, where applicable). The spatial coordinates based on the addresses recorded in the ads were added to apply spatial regression models.

## 4. Results

### *4.1. Standard Ordinary Least Squares Estimation*

First, the standard hedonic regression approach was employed to investigate the impact of EPCs on listing prices of properties located in both cities. For the case of Barcelona, the variables strongly influencing the model fitting were identified, such as the distance to the sea, the presence of a swimming pool (especially in more recent buildings), and air conditioning, present in 54% of cases in the sample. Table 2 shows the estimates of the coefficients of the variables included in the model for the case of Barcelona.

**Table 2.** Barcelona case (3224 observations). Regression model results—semi-log model (OLS).

| | Coefficients | | t | Significance | 95.0% Confidence Interval | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|
| Independent Variables | β | SE | | | Lower bound | Upper bound | Tolerance | VIF [a] |
| Constant | 11.225 | 0.030 | 370.1 | 0.000 | 11.166 | 11.284 | | |
| Floor area (m$^2$) | 0.009 | 0.000 | 67.35 | 0.000 | 0.008 | 0.009 | 0.861 | 1.161 |
| Dwelling's level | 0.022 | 0.003 | 7.915 | 0.000 | 0.016 | 0.027 | 0.930 | 1.076 |
| New/retrofitted | 0.063 | 0.017 | 3.605 | 0.000 | 0.029 | 0.097 | 0.927 | 1.079 |
| EPC | 0.020 | 0.005 | 4.035 | 0.000 | 0.011 | 0.03 | 0.948 | 1.054 |
| Air conditioning | 0.149 | 0.014 | 10.58 | 0.000 | 0.122 | 0.177 | 0.871 | 1.148 |
| Year | 0.06 | 0.007 | 8.707 | 0.000 | 0.046 | 0.074 | 0.98 | 1.021 |
| Swimming pool | 0.426 | 0.139 | 14.84 | 0.000 | 0.369 | 0.482 | 0.948 | 1.055 |
| Lift | 0.208 | 0.017 | 12.43 | 0.000 | 0.176 | 0.241 | 0.828 | 1.208 |
| Highway ramp | 0.0001 | 0.000 | 10.87 | 0.000 | 0.000 | 0.000 | 0.895 | 1.117 |
| Urban parks | 0.00005 | 0.005 | 4.035 | 0.000 | 0.000 | 0.000 | 0.796 | 1.256 |
| Sea coast | −0.00008 | −0.183 | −19.7 | 0.000 | 0.000 | 0.000 | 0.979 | 1.021 |
| Estimated SE | 0.376 | $R^2$ | 0.734 | Adjusted $R^2$ | 0.733 | Durbin–Watson test | | 1.427 |

[a] **Variance Inflation Factor**
Dependent variable: LN_PRICE (€)
Stepwise regression

The coefficient of the variables obtained the expected sign. Concerning the year of advertisement, listing prices increased compared to 2014. In recent years, Barcelona has experienced a considerable period of economic recovery [49]. As far as the location variables are concerned, the values are to be understood as the reduction or increase of the properties, respectively, with the negative or positive sign, and relating to the distance from the reference point. As expected, the apartments located near the coast have a greater value than those located near motorway ramps, which signals a negative effect coming from noise and atmospheric pollution as well as the periphery city associated to the location of such infrastructures. The coefficient of the distance from the main urban parks had a positive sign. This means that the further away you go from a park, the more the value of the properties grows, since the peripheral areas are largely equipped with these amenities, especially because natural areas located at the periphery of the city (i.e., Collserola) have been transformed into urban parks. On the other hand, the non-significance of proximity to a metro station may be produced by the fact that most of the displacements in the municipality of Barcelona is non-motorized mobility. Compared to other typical characteristics of the sample building stock, such as air conditioning and the presence of a swimming pool, the coefficient for the energy class was lower. Each step of the energy class ranking allowed only a 2% increase in the total listing price, with an increase of 12% passing from a rank G to A.

Even in the case of Turin, the coefficients had the right sign, quantities, and significance (Table 3). Compared to Barcelona, Turin experienced a slower period of economic recovery, witnessed by the negative sign of the time variable. The Italian real estate market has experienced a sharp fall in property prices in recent years compared to other EU countries. The national economy is one of the main factors. Italy had an economic growth trend lower than the average of other European countries, but even when the Italian economy grew at 1.6%, the real estate market continued to fall. Moreover, more stringent criteria are adopted by the banks to obtain a mortgage. Credit institutions have low liquidity and, therefore, are unavailable to provide loans. On the other hand, the price of real estate is influenced by the number of homes for sale. In fact, the number of homes for sale is increasing, resulting in lower prices.

**Table 3.** Turin case (15,228 observations). Regression model results—semi-log model (OLS).

| | Coefficients | | t | Significance | 95.0% Confidence Interval | | Collinearity Statistics | |
|---|---|---|---|---|---|---|---|---|
| **Independent Variables** | **β** | **SE** | | | **Lower bound** | **Upper bound** | **Tolerance** | **VIF** |
| Constant | 10.230 | 0.019 | 549.12 | 0.000 | 10.194 | 10.267 | | |
| Floor area (m$^2$) | 0.11 | 0.713 | 171.34 | 0.000 | 0.011 | 0.011 | 0.915 | 1.093 |
| New/retrofitted | 0.211 | 0.145 | 33.829 | 0.000 | 0.199 | 0.223 | 0.863 | 1.159 |
| EPC | 0.068 | 0.156 | 35.625 | 0.000 | 0.064 | 0.072 | 0.822 | 1.216 |
| Year | −0.02 | −0.025 | −6.285 | 0.000 | −0.026 | −0.014 | 0.995 | 1.005 |
| Lift | 0.261 | 0.160 | 38.509 | 0.000 | 0.248 | 0.274 | 0.922 | 1.084 |
| Metro station | −0.00002234 | −0.059 | −12.902 | 0.000 | 0.000 | 0.000 | 0.761 | 1.313 |
| Highway ramp | 0.00004520 | 0.122 | 26.041 | 0.000 | 0.000 | 0.000 | 0.734 | 1.362 |
| Urban parks | −0.0000114 | −0.012 | −2.925 | 0.003 | 0.000 | 0.000 | 0.981 | 1.019 |
| Estimated SE | 0.355 | $R^2$ | 0.761 | Adjusted $R^2$ | 0.761 | Durbin–Watson test | | 1.755 |

Dependent variable: LN_PRICE
Stepwise regression

Another variable resulting from the stepwise regression model was the distance of the major urban infrastructures. Also in this case, the vice-versa distance to highway ramps had a negative influence on the market price. Turin has a single subway line that significantly impacts on real estate prices. Unlike Barcelona, Turin's main parks are located in the city center and market values are affected positively. The impact of the energy class on prices in Turin was equal to +6.8% of the listing price for each class jump from G to A, almost 5% more than in Barcelona.

## *4.2. Spatial Estimation*

Some studies [8,14,21] include socio-economic variables in the hedonic regression in order to consider the impact of income, professional status or education of the population characterizing the market area. Often the social attributes are introduced in the model by referring to the census data. Since these variables vary quite rapidly over time, it is difficult to refer to census data collected only every ten years. Moreover, in the case of Barcelona, since the last 2011 census was based on a non-representative survey at the census tract level, the last available information dates back to the year 2001.

Additionally, socio-economic effects are not limited to administrative boundaries of cities. In this perspective, including explicit socio-economic attributes in the econometric model does not resolve the spatial autocorrelation issue, since the social classes remain segregated along with the city and this is reflected in the building structure and location choice.

Global spatial autocorrelation analysis was performed for each dataset. For this purpose, the free software GeoDa was employed [66]. The graphs below show the presence of spatial autocorrelation that can be distinguished in four quadrants of the Moran's scatterplot. Observations with positive autocorrelation fall into quadrants I and III. In quadrant I, the relation was established for high values (high–high relation), both for the variable LN_PRICE and spatial lagged values. In quadrant III, the values were both low (low–low relation). In quadrants II and IV, the autocorrelation was negative. For the points in quadrant IV, low values of the variable LN_PRICE was associated with high values of the lagged one (low–high relation). Vice-versa in quadrant II, where there was a high–low relationship.

Once selected, the contiguity weight matrix, the Moran's Index (MI), was computed. Figure 2; Figure 3 show the autocorrelation between the natural logarithm of the total price of each transaction (LN_PRICE) and the average value of the neighboring ones (lagged LN_PRICE) for the city of Barcelona and Turin, respectively.

For the Barcelona case, the graph shows a great level of spatial autocorrelation (0.604113 MI). While the Moran's scatterplot indicated a discrete level (0.264879 MI) of autocorrelation in Turin, due probably to the more differentiated building stock (Figure 3). Moreover, GeoDA represents the results of the autocorrelation analysis in a cartographic way, favoring the creation of clusters in space through the LISA (local indicators of spatial association) tool. In particular, the dark red point indicates the areas where the relationship assumes the high–high value; light red, high–low areas, light blue points, low–high areas, and dark blue points, areas with low–low values. The observations for which relationships are not significant ($p$-value > 0.05) are in grey. In the case of Barcelona, high–high relationships were remarkably present in high income area, while low–low were basically present in working class areas as well as those dominated by non-communitarian immigration. No significant spatial correlations are present in mixed neighborhoods. Such extremes illustrate the socio-economic control introduced in HPM when solving spatial autocorrelation issues.

Since a spatial dependence of prices was identified, the SAR and SEM models were developed for both cities. The choice of an appropriate spatial model that best describes the regression function is defined by the statistical test of the Lagrange multiplier (LM). The GeoDA provides the LM for both SAR and SEM; the best model is that depicting the highest indicator value. If both are significant, robust LM lag and robust LM error should be considered. Given the Moran Index for the Barcelona case, the SAR model was expected to perform better. This was also confirmed by the minimized AIC and SC indicator values. For the lag model, we also had a new variable (W_LN_Price) equal to Lag coefficient $\varrho$. This variable measures the spatial dependence in the sample calculating the influence on observations by their neighboring values. Besides, in the SEM model, a new indicator emerges: the Lambda coefficient. A positive and significant $\lambda$ means that the general model fit is improved.

The best performing spatial model is the SAR model, with the highest log likelihood value, and the lowest AIC and SC criteria. For the case of Barcelona, $R^2$ increased from 0.76 of the OLS to 0.82 of the SAR models (Table 4). In Barcelona, the properties' listing prices were influenced by nearby observations through a spill-over effect. On the other hand, in Turin, where the building stock is likely more differentiated and there is also more geographical heterogeneity, the SEM performed better, taking into account the lack of spatial correspondence, and better corrected the omitted variables (Table 5). The correction of the spatial autocorrelation allowed to improve the model fitting. Briefly, the impact of the EPC in Barcelona reached a percentage of 1.88% on the property listing price considering the SAR model. In Turin, the SEM model estimated an increase given by the EPC of 6.33% for each rating level from G to A.

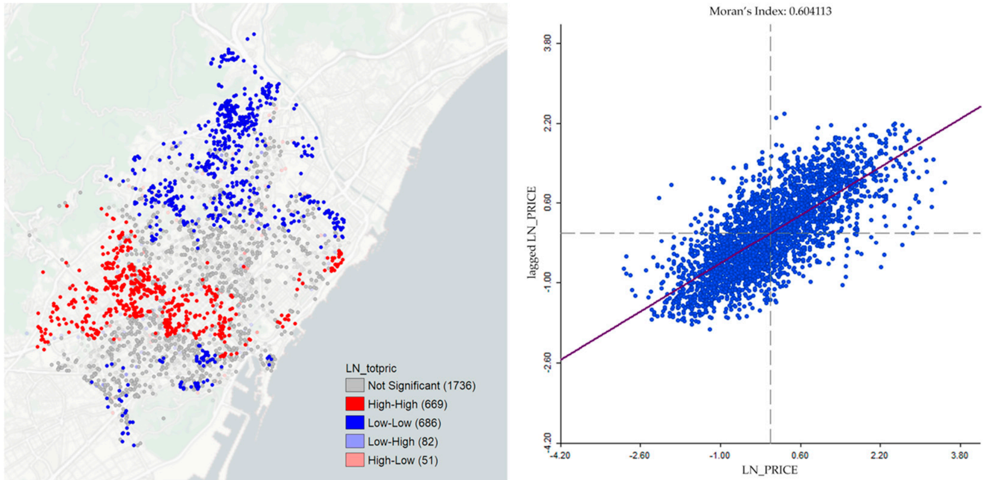


**Figure 2.** LISA (Local Indicators of Spatial Association) cluster significance map for the Barcelona dataset on the **left** and the Moran's scatterplot on the **right**.

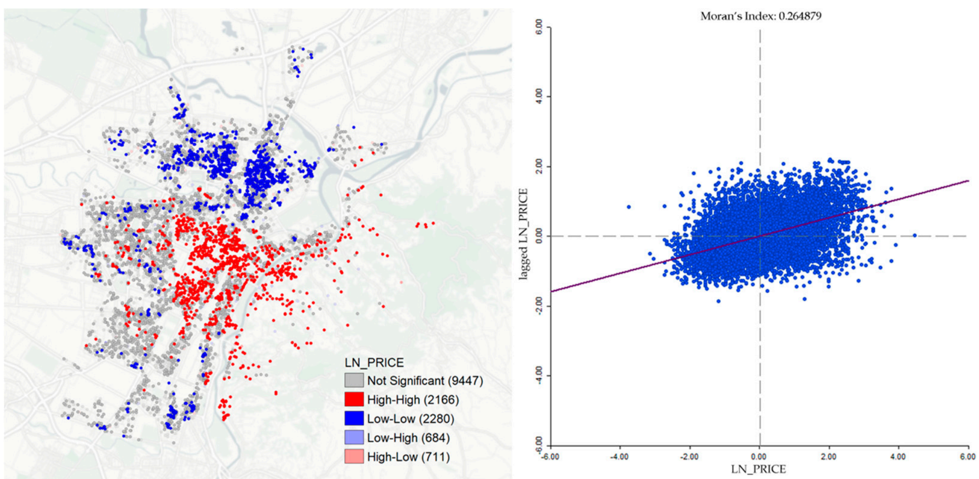


**Figure 3.** LISA cluster significance map for the Turin dataset on the **left** and the Moran's scatterplot on the **right**.

**Table 4.** Spatial regression models for the Barcelona case.

| | SPATIAL LAG MODEL | | | | SPATIAL ERROR MODEL | | | |
|---|---|---|---|---|---|---|---|---|
| | Coefficients | | | | Coefficients | | | |
| Independent Variables | β | SE | t | Significance | β | SE | t | Significance |
| W_LN_Price | 0.4436 | 0.01201 | 36.934 | 0.000 | | | | |
| Lambda (λ) | | | | | 0.36606 | 0.02542 | 14.396 | 0.000 |
| (Constant) | 5.97268 | 0.14445 | 41.346 | 0.000 | 11.3458 | 0.03417 | 331.96 | 0.000 |
| Floor area (m$^2$) | 0.00702 | 0.00011 | 60.045 | 0.000 | 0.0077 | 0.00012 | 63.408 | 0.000 |
| Dwelling's level | 0.01745 | 0.00224 | 7.774 | 0.000 | 0.01986 | 0.00244 | 8.128 | 0.000 |
| New/ retrofitted | 0.0669 | 0.01433 | 4.666 | 0.000 | 0.06904 | 0.01554 | 4.440 | 0.000 |
| EPC | 0.0188 | 0.00416 | 4.518 | 0.000 | 0.0182 | 0.00462 | 3.94 | 0.000 |
| Air conditioning | 0.1272 | 0.01158 | 10.98 | 0.000 | 0.13397 | 0.01255 | 10.669 | 0.000 |
| Year | 0.04848 | 0.00566 | 8.565 | 0.000 | 0.05201 | 0.00612 | 8.646 | 0.000 |
| Swimming pool | 0.2761 | 0.023804 | 11.602 | 0.000 | 0.3407 | 0.02759 | 12.347 | 0.000 |
| Lift | 0.14912 | 0.013915 | 10.716 | 0.000 | 0.1979 | 0.01559 | 12.693 | 0.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Highway ramp | 0.00002 | 0.000007 | 3.509 | 0.000 | 0.00012 | 0.000 | 5.732 | 0.000 |
| Urban parks | | | | | 0.00007 | 0.00001 | 6.651 | 0.000 |
| Sea coast | 0.00004 | 0.000003 | −13.19 | 0.000 | −0.00009 | 0.000006 | 15.826 | 0.000 |
| LN_PRICE (mean) | 12.547 | $R^2$ | 0.8202 | | LN Price (mean) | 12.547 | $R^2$ | 0.7926 |
| Akaike criterion | 1661.64 | Schwarz criterion | 1734.58 | | Akaike criterion | 1877.12 | Schwarz criterion | 1950.06 |
| Log Likelihood | −818.82 | Estimated SE | 0.306354 | | Log likelihood | −926.55 | Estimated SE | 0.32903 |
| Lag coefficient (Rho) | 0.4436 | | | | Lag coefficient (Lambda) | 0.3666 | | |
| | Value | Probability | | | | Value | Probability | |
| LM (lag) | 1458.20 | 0.000 | | | LM (error) | 1231.84 | 0.000 | |
| Robust LM (lag) | 485.54 | 0.000 | | | Robust LM (error) | 256.58 | 0.000 | |

**Table 5.** Spatial regression models for the Turin case.

| | SPATIAL LAG MODEL | | | | SPATIAL ERROR MODEL | | | |
|---|---|---|---|---|---|---|---|---|
| | Coefficients | | t | Significance | Coefficients | | t | Significance |
| **Independent Variables** | β | SE | | | β | SE | | |
| W_LN_Price | 0.22783 | 0.00810 | 28.102 | 0.000 | | | | |
| Lambda (λ) | | | | | 0.4004 | 0.01386 | 28.87 | 0.000 |
| (Constant) | 8.17181 | 0.0938 | 87.098 | 0.000 | 10.7578 | 0.03440 | 440.87 | 0.000 |
| Floor area (m²) | 0.01067 | 0.00006 | 166.33 | 0.000 | 0.01087 | 0.00006 | 170.12 | 0.000 |
| New/ retrofitted | 0.20964 | 0.00602 | 34.789 | 0.000 | 0.20745 | 0.006 | 34.575 | 0.000 |
| EPC | 0.06306 | 0.00183 | −34.28 | 0.000 | 0.06324 | 0.00188 | −33.6 | 0.000 |
| Year | −0.01819 | 0.00304 | −5.966 | 0.000 | −0.01782 | 0.00305 | −5.85 | 0.000 |
| Lift | 0.239513 | 0.006580 | 36.398 | 0.000 | 0.242766 | 0.00665 | 36.45 | 0.000 |
| Metro station | −0.00001 | 0.000001 | −7.314 | 0.000 | −0.00001 | 0.000003 | −5.426 | 0.000 |
| Highway ramp | 0.00002 | 0.000001 | 14.296 | 0.000 | 0.00005 | 0.00002 | 18.03 | 0.000 |
| Urban parks | −0.00001 | 0.000003 | −5.449 | 0.000 | −0.00002 | 0.00004 | −5.21 | 0.000 |
| LN Price (mean) | 11.84 | $R^2$ | 0.7757 | | LN Price (mean) | 11.84 | $R^2$ | 0.7787 |
| Akaike criterion | 11,002.5 | Schwarz criterion | 11,078.5 | | Akaike criterion | 10,988.8 | Schwarz criterion | 11,057.5 |
| Log Likelihood | −5491.26 | Estimated SE | 0.345628 | | Log Likelihood | −5485.4 | Estimated SE | 0.34335 |
| Lag coefficient (Rho) | 0.22783 | | | | Lag coefficient (Lambda) | 0.40044 | | |
| | Value | Probability | | | | Value | Probability | |
| LM (lag) | 1053.46 | 0.000 | | | LM (error) | 1215.14 | 0.000 | |
| Robust LM (lag) | 282.70 | 0.000 | | | Robust LM (error) | 444.38 | 0.000 | |

## 5. Conclusions

The Directive 2010/31/EU introduced the Energy Performance Certificate (EPC) in Europe in order to promote energy efficiency in the real estate market. However, different rating scales and different indicators have been adopted by the member states to define the levels of the evaluation scale. This paper highlighted the difficulties in comparing the impacts of the EPC on real estate values in different regions of the EU, even though that the Directive wished to establish a standard valid rule.

An academic research branch has developed several applications for the evaluation of the effects of the EPC on market prices in residential and commercial buildings through the HPM proposed by Rosen. Concerning the residential sector, the literature review confirmed the existence of a green premium for buildings in best performing energy labels. However, the effect of the EPC on the market price differs in European countries. If many real estate markets have been analyzed in northern Europe, few cities in the Mediterranean area have been investigated. This study aims to close the gap comparing the effects of the energy class on multi-family buildings' prices in two southern European cities.

Starting from a sample of real estate values located in Turin and Barcelona, the study applied different models based on the HPM to estimate the EPC appreciation by consumers. At the same time, the importance of considering and taking under control the complex spatial dynamics of the urban residential market was considered.

The cases of Turin and Barcelona showed the differences relating to the application of the same policy, despite the mandatory nature of the EBPD standard. Indeed, in Turin, almost all the real estate ads had information about energy performance, while in Barcelona, this information was often provided in the notarial deed. A lack of homogeneity in information on the energy efficiency of buildings in terms of EPC led to a different impact of the ECP on prices. In Barcelona, the EPC affected property price up to 1.88% for each rating level from G to A. In Turin, the HPM model estimated an increase given by the EPC of 6.33%. The two cases confirm what has already been discovered elsewhere, namely, that in colder climate zones, where the HDD index is higher, there is a greater probability that the buyer regards the EPC as a valid indicator of energy consumption or savings. On the contrary, in warmer areas, where energy devoted to heating is not too high, the consumer will continue to appreciate the single technical and structural components of the building, such as air conditioning and swimming pools. On the other hand, this behavior does not seem totally irrational, although the so-called energy efficiency gap [67,68] has not been overcome. Indeed, this study shows that in Europe and in a sector where information plays a significant role [69], the process of the uniform application of a green label to the real estate stock cannot be considered as yet concluded.

Despite this implementation deficit, the EPC can help to predict what will be the future annual cost for heating or cooling and domestic hot water of a property.

This study confirmed that the implementation of the EPC schemes is still irregular and needs to be strengthened. The requirements of the EPBD recast should be fully implemented in all Member States through a standardized EPC rating model. Connecting EPCs to political and financial support programs could significantly increase the number and quality of energy-saving renovations and make consumers aware of efficient buildings [70].

As a future perspective of the study, it would be of scientific interest to include socio-economic and demographic variables in the Hedonic Model in order to control for the effect of neighborhood variables in the determination of the price of residential properties [71]. Further work could also consider the application of methods belonging to the stated preferences of families to the considered case studies in order to validate the obtained findings [72–74].

**Author Contributions:** Conceptualization, M.B., F.D. and C.M.-D.; Methodology, F.D.; Validation, M.C.B, M.B., F.D and C.M.-D.; Resources, M.B. and A.C.; Writing—original draft preparation, M.B. and F.D.; Writing—review and editing, M.C.B, M.B., F.D. and C.M.-D.; Visualization, F.D.; Funding acquisition, M.C.B. and C.M.-D.

**Funding:** The work illustrated in the present paper was developed in the EnerValor (MINECO/FEDER BIA-2015-6306-R) and VALIUM (Valuation for Integrated Urban Management—Politecnico di Torino) research projects.

**Acknowledgments:** The database of Turin City used in this work is continuously implemented thanks to the collaboration with the online immobiliare.it real estate agency. Special thanks thus go to immobiliare.it for the positive and continuous collaboration. In the case of Barcelona, the authors want to recognize the continued support of Habitaclia in providing relevant information.

**Conflicts of Interest:** The authors declare no conflict of interest.

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