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# A Well-Being Index for Housing in the Central Districts of Madrid, Spain

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**Abstract:** The internal characteristics of dwellings and their level of accessibility to basic services have traditionally been the main variables in establishing their level of quality; however, in large cities, problems associated with traffic and environmental quality are becoming increasingly important because of their impact on people's quality of life. This paper aims to build a well-being index for dwellings in the central districts of Madrid that can help the urban managers to take decisions increasing citizens' well-being. For this purpose, we have developed an indicator using the P2-distance method on a database of variables related to environmental quality, and on the other hand, variables related to the characteristics of the dwelling. We find that, in general, the distance to services variables correlates negatively with the well-being index as we expected. On the other side, a positive and unexpected correlation is observed between the well-being index and the variables of pollution and noise, which indicates that these variables are usually higher in the points best located with respect to basic services, places that we could consider as service centers of the central almond. Therefore, the index allows urban planners to test complex solutions in presence of the trade-offs between elements that affect negatively the well-being such as noise or pollution, versus positive variables such as higher density of services availability. DOI: 10.1061/(ASCE)UP.1943-5444.0000793. © 2021 American Society of Civil Engineers.

**Author keywords:** Housing well-being; Environmental quality; Socioeconomic variables; Accessibility.

## Introduction

The strong growth that developed economies have experienced since the second half of the 20th century, and developing economies from the last quarter of the same century, has led to a significant environmental impact as a consequence of the inadequate management of natural resources. The utilization rate is higher than the regeneration rate for the natural renewable resources, as well as higher than the rate of creation of renewable substitutes for the nonrenewable natural resources (Van Ierland et al. 2001, p. 107).

The relationship between economic growth and environmental degradation resembles an inverted U (Kuznets Environmental Curve, KEC) (Kuznets 1955). The reason for this behavior would lie in the different attention that economies pay to

environmental objectives throughout their economic development: in the short term, economic growth generates an environmental deterioration, but in the long term this situation becomes as the level of income per capita of the economies increases and, with it, their level of development. However, subsequent studies do not seem to have yielded unequivocal results in this regard (Shafik 1994).

On the other hand, different studies (Costantini and Martini 2006; Catalán 2014; Koilo 2019) confirm that environmental improvements do not depend exclusively on economic growth. Aspects such as energy efficiency (Cantos and Lorente 2011), technological innovation, and policies for the protection of biodiversity and the conservation of natural areas, play a relevant role (Bhattacharyya and Ghoshal 2010). In short, the countries that have greater economic freedom are those that, in general, also have better environmental performance, as reflected in the Environmental Performance Index (EPI), established by Yale University (Wendling et al. 2020) and the Heritage Foundation's Index of Economic Freedom (IEF) (Miller et al. 2020).

The publication of the Brundtland Report (United Nations 1987), in which the term *sustainable development* was coined, was a turning point from which international institutions, governments, and public opinion began to become aware of environmental problems. Subsequently, different international organizations and institutions (United Nations and its different specialized agencies, the OECD, the European Commission) have launched initiatives such as the Agenda 21 and the Sustainable Development Goals 2015–2030. Regarding the technical and scientific field, it is important to highlight the adoption in 2012 by the United Nations of the Central Framework of the System of Environmental and Economic Accounting (SCAE), the first international statistical standard for environmental and economic accounting (United Nations 2014).

At the same time, we are witnessing the constant increase in the urbanization rate of the world population, with the consequent

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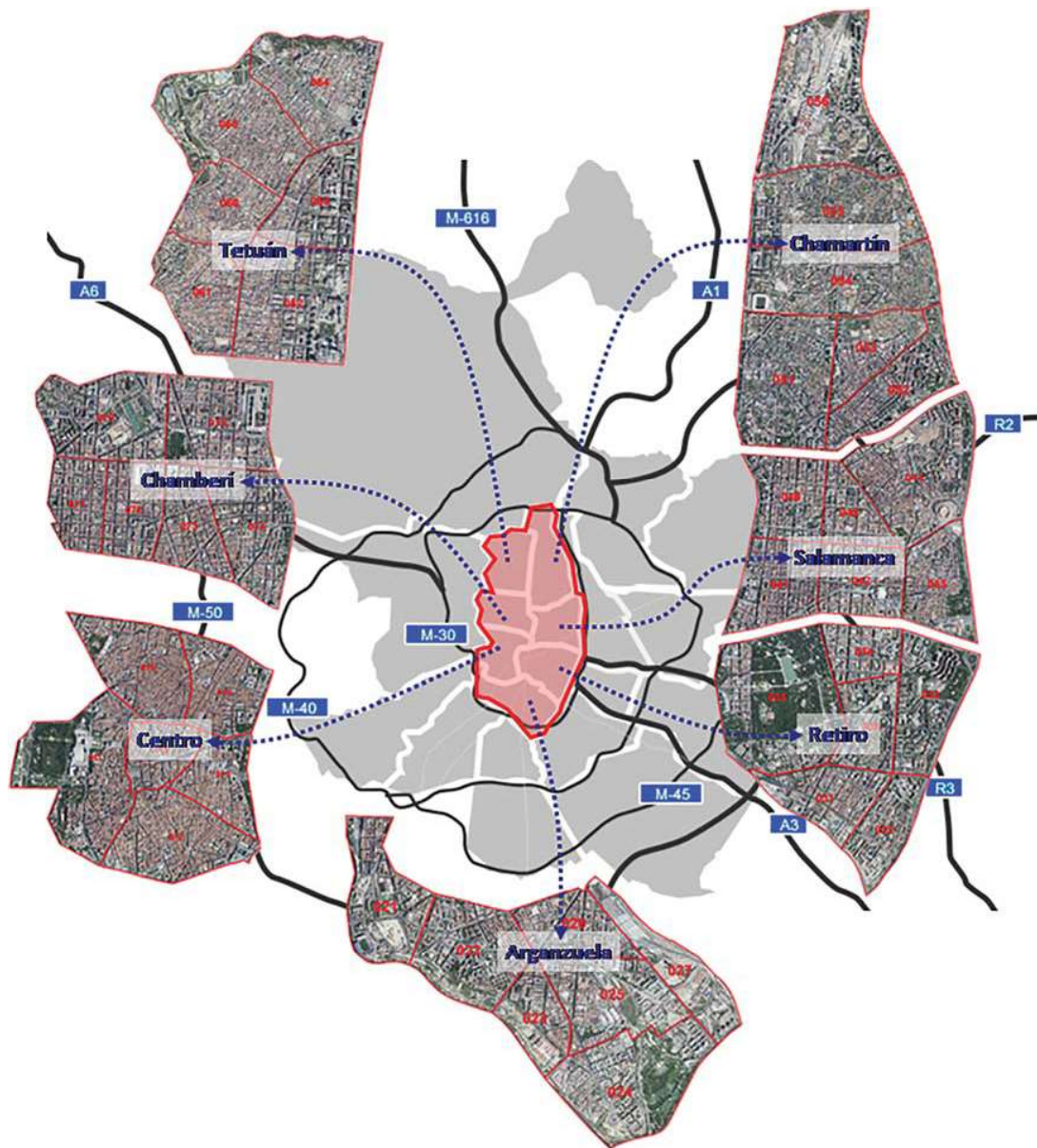
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66	impact generated by the high population density in urban areas	130
67	(Satterthwaite 1993). Currently, more than half of the world's popu-	131
68	lation lives in urban areas and is projected to reach nearly 70% by	132
69	2050. In the developed countries, this percentage reaches almost	133
70	80%. And for the European Union (EU), around 75% of the popu-	134
71	lation lives in urban areas, a percentage that will be around 80% in	135
72	2050 (UNDESA 2019, p. 11).	136
73	Most European cities face a series of environmental problems	137
74	that decrease the quality of life (Zurrita et al. 2015), or even influ-	138
75	ences mental well-being (Lauwers et al. 2021), such as air pollution	139
76	(Azlina and Mustapha 2012; Ozcan 2013), noise (Moreno and	140
77	Martínez 2005), traffic congestion, reduction of green areas (United	141
78	Nations, European Commission 2014, p. 74), or the loss and	142
79	degradation of biodiversity (Tellería 2013).	143
80	To alleviate this situation, the EU is adopting different measures	144
81	such as the approval in 2016 of the EU Urban Agenda, and launching	145
82	different initiatives, such as CIVITAS, The European Urban Knowl-	146
83	edge Network (EUKN), or METREX (Eurostat 2016, pp. 21–23).	147
84	Despite the improvements achieved reducing the urban air pol-	148
85	lution levels, 96% of the European population living in urban areas	149
86	is exposed to concentrations of pollutants exceeding the World	150
87	Health Organization recommendations (EEA 2019, p. 200) and	
88	almost 20% of the urban population lives in areas exceeding at	
89	least one of the air quality standards set by European legislation	
90	(EEA 2019, p. 13).	
91	Likewise, 65% of the European population residing in the main	
92	urban areas is exposed to high levels of noise (United Nations,	
93	European Commission 2014, p. 48). In the case of Madrid, like	
94	any other large city, it suffers significant levels of environmental	
95	and acoustic contamination for which management policies are	
96	defined for guaranteeing a certain level of quality of life (Taboada	
97	2007).	
98	The presence of sufficient green areas affects both pollution and	
99	the quality of life. The presence of vegetation improves air quality	
100	(Lopera 2005), removes dust particles and heavy metals (Czemieli	
101	Berndtsson. Scandinavian Green Roof Institute), reduces the heat	
102	island effect (Priego 2002; Depietri and McPhearson 2017; EEA	
103	2019, p. 177) and acts as an acoustic (Davis et al. 2016) and thermal	
104	insulator (Reyna and Márquez 2013).	
105	Environmental psychology finds that the relationship between	
106	quality of life and environmental quality/hygiene is mediated by	
107	a directly proportional link (Baldí López and García Quiroga	
108	2005). Many authors speak of the pros of living close to nature	
109	since it promotes physical activity and helps develop good habits	
110	(Astell-Burt et al. 2014), the presence of green landscapes reduces	
111	stress (Priego 2002), and generally improves the quality of life as	
112	an individual and as a society. Therefore, environmental quality	
113	due to proximity to green areas turns out to be a very important	
114	dimension for people's well-being (OECD 2011, p. 212).	
115	In the last decades, well-being and quality of life in urban areas	
116	have gained prominence in research works (Goerlich-Gisbert et al.	
117	2019, p. 213). Two reasons that may explain this phenomenon	
118	maybe, on the one hand, the greater demands of individuals	
119	when considering and valuing the environment in which they reside	
120	(Royuela Mora et al. 2008), as well as the relevance that quality of	
121	life is playing in the strategies carried out by the cities to attract	
122	business investment and skilled labor (Rogerson 1999). In some	
123	way, cities offer a set of urban services to their residents (Insch	
124	and Florek 2010).	
125	Definitively, the impact of spatial and environmental character-	
126	istics on the well-being of residents is as important as the impact	
127	produced by socioeconomic and sociodemographic factors	
128	(Brereton et al. 2008). In this context, this paper proposes an	
129	index that can be used to measure the well-being effects of urban	
	planning decisions for the citizens, incorporating environmental-	130
	related aspects such as pollution and noise, in comparison with	131
	other elements such as proximity to basis services.	132
	Thus, considering the aforementioned, the main objective of this	133
	work is to build a well-being index for the estates in the central dis-	134
	tricts ( <i>central almond</i> ) of Madrid city, based on two types of vari-	135
	ables: on the one hand, environmental quality variables and, on the	136
	other hand, socioeconomic variables linked to the houses. The anal-	137
	ysis of the relationship between the variables used to generate the	138
	well-being index and the index itself, and the study of the distribu-	139
	tion in the space of the level of well-being associated with housing	140
	will be secondary objectives of this study. Regarding the influence	141
	of environmental and socioeconomic variables on the well-being	142
	levels, our starting hypotheses establish that high values of pollu-	143
	tion (acoustic and chemical) are related to low values of well-being	144
	in homes, whereas high values of price, housing surface, and acces-	145
	sibility to basic services are associated with high levels of well-	146
	being. Regarding the distribution of the levels of well-being of	147
	the houses within the central almond of Madrid, we start from	148
	the hypothesis that the highest levels are located in the central dis-	149
	tricts and the lowest levels in the peripheral districts.	150
	<b>Material and Methods</b>	151
	<b>Study Area</b>	152
	The study area is the <i>central almond</i> of the city of Madrid (Fig. 1),	153
	capital of Spain, located in the Autonomous Community of Madrid.	154
	Geographically, Madrid is located in the center of the Iberian Pen-	155
	insula (latitude: 40.4893538, longitude: −3.6827461) and at a	156
	height of 667 m above sea level.	157
	According to the Köppen climate classification (1918), Madrid	158
	has a climate between cold semiarid (BSk) and typical Mediterra-	159
	nean (Csa) (Iberian Climate Atlas, AEM 2011). In addition, its popu-	160
	lation and activity volume causes it to suffer the heat island effect	161
	(García and Martilli 2012), which causes thermal inversion and	162
	temperatures to rise mainly at night due to the return to the atmo-	163
	sphere of the heat stored by asphalt and buildings (Tumini 2010;	164
	Godoy 2014), causing negative effects to the well-being of those	165
	living in the center of the city during the hot summers.	166
	Madrid is the most populous municipality in Spain with	167
	3,223,334 inhabitants (INE 2018) on an area of 604.45 km <sup>2</sup> and is	168
	divided into a total of 21 districts of which the following are the cen-	169
	tral area of Madrid: Centro, Arganzuela, Retiro, Salamanca, Chamar-	170
	tín, Tetuán, and Chamberí. These seven districts of the central	171
	almond are those that constitute the study area of the present work.	172
	The spatial units that serve as the basis for this study split a sam-	173
	ple of 5,534 homes for sale in the central almond published on the	174
	Idealista real estate brokerage portal in 2018.	175
	<b>Methodology</b>	176
	The methodology of the present study is structured in four phases:	177
	first, the variables for the analysis are selected; second, a database	178
	is constructed with those variables; third, the environmental- and so-	179
	cioeconomic well-being index for the houses is obtained; and fourth,	180
	the results obtained at the housing and district levels are analyzed.	181
	<b>Phase 1. Variables Selection</b>	182
	Taking into account the objective of the study, the variables se-	183
	lected for the analysis are those whose variation is understood to	184
	also generate a variation in the level of well-being associated	185
	with housing. The special circumstance, in this case, has to do	186





**Fig. 1.** Study area. Madrid central area districts with their road network. Compiled by the authors based on the district map of the Madrid City Council website. (Base maps by Cartography Department Madrid City Council, Geoportal.)

with the fact that the main units of analysis are the houses in the central almond of Madrid since some of the information available at higher levels of disaggregation will not be at the house level; therefore, all the variables have had to be generated especially for the purpose of this work. These variables can be divided into two groups: environmental variables and socioeconomic variables linked to housing (Fig. 2).

## Phase 2. Database Construction

The variables indicated in the previous phase have been used to develop the necessary database for the construction of the well-being indicator for the houses in the central almond of Madrid. In this Phase 2, those variables are described, considering that, although well-being is a subjective concept, there would be a broad consensus on the influence of all of them on this concept.

**Contamination.** In cities, both mobile (road traffic) and stationary sources (industries, residential uses of air conditioning, and waste

disposal processes) are key polluting agents. The pollutants that have been considered for this work are secondary pollutants—produced from transformations of primary pollutants derived directly from emission sources—that cause photochemical contamination or photochemical smog and the heat island effect typical of cities (Correa et al. 2003; Kevern et al. 2012). According to Wendling et al. (2013), specifically, the contaminants that contribute to photochemical contamination and the heat island effect are carbon monoxide (CO), nitrogen monoxide (NO), nitrogen dioxide (NO<sub>2</sub>), and ozone (O<sub>3</sub>) (Ballester 2005). The data have been extracted from the register of the 26 measuring stations of the city available through the open data portal of the Madrid City Council for the period 2007–2017.

Since each pollutant is expressed in a different unit, to allow comparisons between them, we have considered the average amount of each pollutant in the period considered with respect to its legal limit according to Royal Decree 102/2011 of January 28



Environmental variables	Socioeconomic variables linked to housing	
Air quality	Price	Surface
Noise	Distance to: <ul style="list-style-type: none"> <li>- Nuevos Ministerios (economic center)</li> <li>- Sol (administrative center)</li> <li>- international airport Adolfo Suárez - Madrid Barajas</li> <li>- nearest transport node</li> <li>- nearest commuter network stop</li> <li>- nearest subway station</li> </ul>	Minimum distance to: <ul style="list-style-type: none"> <li>- service area</li> <li>- shopping center (mall)</li> <li>- hypermarket</li> <li>- hospital</li> <li>- nightlife area</li> <li>- M-30 ring road</li> <li>- M-40 ring road</li> </ul>
Traffic density (as an indicator of congestion)	Population density	
Distance to green areas		

Fig. 2. Variables under study (20).

regarding improvement of air quality.

% Pollutant

$$= \frac{\text{Average level of pollutant in the period 2007–2017}}{\text{Legal limit}} \times 100 \quad (1)$$

Starting from that derivative variable, for each pollutant and measurement station, we performed rasterization and interpolation processes in order to obtain values for the entire central almond and therefore for the points that represent the location of the houses (Velázquez et al. 2019).

**Traffic.** The level of traffic pressure is calculated from the average traffic intensity (total vehicles) data from 1,961 measurement points of the Madrid traffic surveillance network, available through the open data portal of the Madrid City Council, for the period 2012–2013. Since the measurement points are not evenly distributed among the districts and to avoid differences in traffic intensity due to the greater or lesser number of points per district, the following transformation is carried out to generate the variable *traffic*:

$$\% \text{ traffic} = \frac{\text{Total vehicles/District}}{\text{Number of sections/District}} \times \frac{\text{District surface}}{\text{Total surface}} \quad (2)$$

From here, and in order for the traffic to be measured on a scale from 0 to 100, the variable has been transformed again, assigning the value 100 to the highest value (Velázquez et al. 2019). Finally, the variable is rasterized to have the intensity of the traffic throughout the central almond.

**Noise.** Noise is considered a problem in large cities such as Madrid due to the sounds from continuous sources such as road traffic or intermittent sources such as those caused by leisure areas. Although the ability to tolerate noise depends to the greater or lesser degree in which its main components are presented—frequency, intensity, and duration. In general, noise in large cities produces constant uncomfortable auditory sensations that can repeatedly cause damage to people's health (Letter of noise control services, 2018).

The noise level per dwelling has been obtained using the records of the 32 noise measurement stations of the city available through the open data portal of the Madrid City Council for the 2012–2017 period. Specifically, the base variable has been the sound pressure level with frequency weighting A—filter used in the transport noise domain—and Slow Temporal Weighting (it is used to measure the noise that does not fluctuate rapidly. The time constant is 1 s) that is

exceeded during 50% of the observation time. Starting from this variable, to have a complete noise map and thus see the sound pressure level not only at the points of the measuring stations but throughout the central almond and therefore at the points where the homes are located, it has been necessary to carry out the IDW rasterization and interpolation processes.

**Distance to Green Areas.** There is a large bibliography that describes the benefits that green areas in cities have on the quality of life of their inhabitants. The improvement of environmental quality associated with these areas has a precise impact on several of the aspects that make up the quality of life of citizens, first of all, on environmental stress and specifically on air and noise pollution, visual pollution, and road safety, as stated by Gómez (2000). Vegetation is presented as an ally in improving environmental conditions since it contributes to the reduction of pollutants (Dimoudi and Nikolopoulou 2003).

In this case, starting from the data on green areas on the official website of the Madrid City Council, the distance of each dwelling in the central almond to the closest green area is obtained.

**Price and Surface of the House.** The dwellings that are taken into account for the analysis, as well as their price in euros and their surface in square meters, have been obtained from the Idealista real estate brokerage website for 2015. It is easy to understand that the surface of the home has a positive influence on the well-being that it provides, and also that a higher price is associated with better characteristics, so *price* is introduced as a variable related to the well-being associated with housing.

**Distance Variables.** This section includes a list of 14 variables of the minimum distance between each of the dwellings in the central almond and a series of services related to leisure (distance to a nightlife area), transportation (distances to the closest entrances to the M-30 and M-40 ring roads, distances to transport hubs, subway and commuter network stations and distance to the airport), to superstores (distance to supermarket and hypermarket), to health services (distance to a hospital), to the tourist and financial nerve centers of the city (distance to Sol and Nuevos Ministerios) and to a service area. All these variables constitute a set of accessibility measures to basic services and, therefore, closer proximity to them (shorter distance) implies a higher level of well-being associated with housing. It is important to mention that the distances to the services that have been considered are always the minimum distances; for example, in the case of the distance to metro stop variable, the distance to the nearest metro stop is considered.

**Population Density.** The population density for each dwelling has been obtained as the quotient between the population of the district to which it belongs as of January 1, 2014, and its square kilometers.

### Phase 3. Socioeconomic Well-Being Index Obtaining

The methodology used to obtain a socioeconomic well-being index for houses in the central almond of Madrid is Distance P2 (DP2) (Ivanovic 1977; Pena Trapero 1977; Zarzosa 2005; Montero et al. 2010). Obtaining a synthetic indicator through the DP2 method is an iterative process whose starting point is a matrix  $V$  of dimension  $K \cdot m$ , where  $m$  is the number of observations (dwellings) and  $K$  is the number of variables. Each element  $V_{kj}$  of the matrix represents the value of the variable  $k$  for the observation (dwelling)  $j$ . The sign with which each variable enters the matrix will make an increase or a decrease in the values of each variable and correspond to an improvement or a worsening of the level of well-being of the dwelling.

Subsequently, a distance matrix  $D$  is constructed, in which each element  $d_{kj}$  is defined as follows:

$$d_{kj} = |v_{kj} - v_{kj}^*| \quad (3)$$

where  $v_{kj}^*$  =  $k$ th component of the reference vector  $V_j^* = \{v_{1j}^*, v_{2j}^*, \dots, v_{Kj}^*\}$  for dwelling  $j$ . For each variable, a reference value must be established, and it is usual to consider the minimum value as a reference (Vicéns and Chasco 2001; Sánchez 2011; Somarriba and Pena 2008). So,  $d_{kj}$  measures the distance between variable  $k$  for dwelling  $j$  and the minimum value of the variable. Therefore, a high value in the global indicator constructed will mean greater well-being.

A global indicator of well-being is dimensionless, therefore, in order to express all the variables chosen for the analysis in comparable units, a first global index is calculated as Frechet's Distance (DF) and it takes the following form:

$$DF(j) = \sum_{k=1}^K \frac{d_{kj}}{\sigma_k} = \sum_{k=1}^K \frac{|v_{kj} - v_{kj}^*|}{\sigma_k}; j = 1, 2, \dots, m \quad (4)$$

where  $\sigma_k$  = standard deviation of the variable  $k$ .

However, DF is a concept of distance valid only under the theoretical and unusual situation of noncorrelation between variables. To solve this limitation, the DF must be corrected in order to eliminate a redundant information effect, by obtaining Distance P2 (DP2):

$$DP2(j) = \sum_{k=1}^K \frac{d_{kj}}{\sigma_k} (1 - R_{k,k-1,k-2,\dots,1}^2); j = 1, 2, \dots, m \quad (5)$$

where  $R_{k,k-1,k-2,\dots,1}^2$  = coefficient of determination of the regression of each variable  $k$  with the other variables ( $k-1, k-2, \dots, 1$ ) and expresses in short, the part of the variance of  $k$  that is linearly explained by the rest of the variables. As a result, the correction factor  $(1 - R_{k,k-1,k-2,\dots,1}^2)$  discounts that part of the variance already explained.

The use of DP2 involves a decision about the order of entry of the partial indicators in the process. It must be decided which variable  $k$  enters first, contributing its variance to the global index, which enters second, and so on. In this process, the first variable ( $k=1$ ) will contribute all its information to the global index ( $d_1/\sigma_1$ ), however, the second ( $k=2$ ) will only incorporate the part of its variance that is not correlated with the first, that is  $(d_2/\sigma_2)(1 - R_{2,1}^2)$  and so on. Accordingly, DP2 would take different values depending on the order of incorporation of the variables, so it is important to find a unique and objective entry criterion. Being DF is a compendium of all variables, it seems logical to make a selection taking into account the correlation between each variable

and DF, first entering the variable for which the correlation is greater. Variables have not been weighted to build the index, in order to do not create any subjective bias.

The complete procedure can be summarized in the following five steps:

1. The DF values for each observation are calculated taking into account the vector of minimum reference values  $v^*$ .
2. The correlation coefficients between the partial indicators and DF are calculated to obtain the order in which they will be incorporated into the calculation process of the DP2.
3. The DP is calculated considering the order of entry of the indicators obtained in the previous step. The first global index will be called DP1.
4. The partial indicators are then ordered again according to their degree of correlation with DP1 in order to recalculate the DP. This second DP calculation will be called DP2.
5. The iterative process described in Step 4 is repeated until convergence is reached, that is until the difference between two successive DPs is zero. If convergence is not reached, the first DP index obtained (or the average of the last two) can be chosen.

The well-being index obtained from the whole process has an average of 100, associating the high values of the index with high values in the level of well-being.

### Phase 4. Representation of the Well-Being Cluster Map

Starting from the database with the 20 environmental and socioeconomic variables and after applying the  $P_2$  Distance methodology to obtain synthetic index, the variable *Well-being index* is obtained, which gives a value for each dwelling in the central almond so that well-being will be higher in those homes that have a higher index value. Based on this information, an analysis of the spatial distribution of the well-being index at the household level has been carried out, which will allow for an aggregate analysis at the district level and generate spatial clusters of well-being values. Four clusters of well-being values have been performed based on the K-means clustering methodology (Likas et al. 2003).

## Results

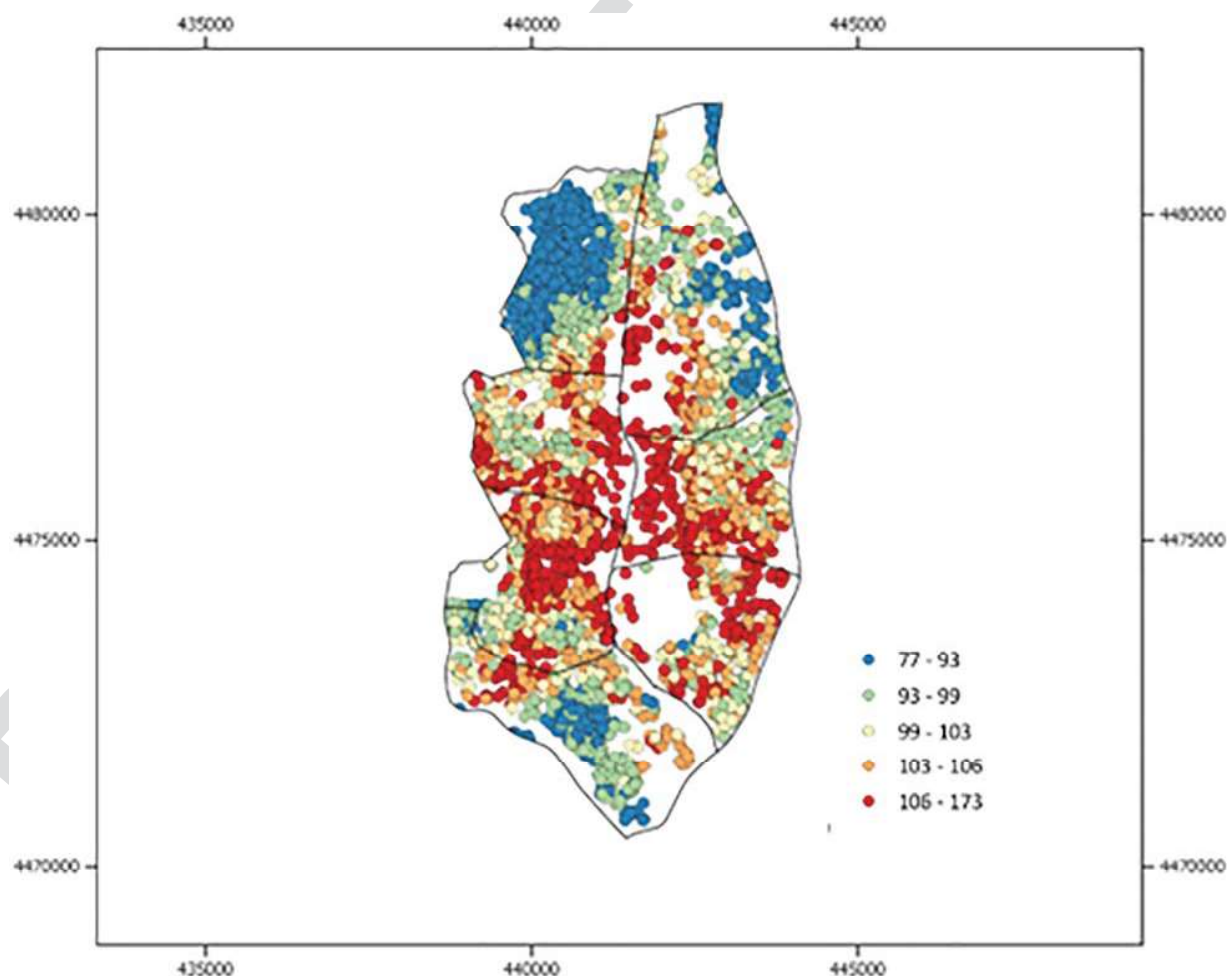
Firstly, by way of exploratory analysis of the variables used for the elaboration of the well-being indicator of the dwellings in the central almond of Madrid, Table 1 shows the path of all of them through their maximum and minimum values, as well as the unit of measurement in which they are expressed and the correlation between each of them and the well-being index. It is important to emphasize that the maximum and minimum values do not refer to those registered in the entire central almond but to the dwellings included in the database considered (from the real estate brokerage website). That is, if we take into account, for example, the variable *distance to the nearest commuter network stop* the minimum value of 15.78 m means that the closest home to a commuter station is 15.78 m, whereas the farthest is 2,759.95 m.

Figs. 3 and 4 show the distribution of the well-being index and the clusters of well-being index of the central almond of Madrid, respectively. Specifically, Fig. 3 shows as many points as dwellings are in the database and the color in which they are represented indicates the well-being value of the dwelling expressed as a multidimensional indicator calculated from all the variables that appear in Table 1. Starting from the value of well-being associated with each dwelling and its spatial distribution within the central almond, the groups or clusters of well-being shown in Fig. 4 can be represented where large areas of homogeneous levels of well-being of the dwellings can be observed.

**Table 1.** Units of measurement, minimum and maximum values of the variables included in the dwelling well-being indicator, and correlation between the variables and the index

T1:1	Variable	Unit	Minimum	Maximum	Correlation with well-being index
T1:2	Contamination	%	66.59	86.20	0.163 <sup>a</sup>
T1:3	Traffic	%	1.23	37.33	−0.144 <sup>a</sup>
T1:4	Noise	%	56.47	62.70	0.226 <sup>a</sup>
T1:5	Minimum distance to green areas	m	0.10	1,252.56	−0.283 <sup>a</sup>
T1:6	Price	€	39,000	120,000,000	0.495 <sup>a</sup>
T1:7	Surface	m <sup>2</sup>	12	2,200	0.400 <sup>a</sup>
T1:8	Distance to Nuevos Ministerios (economic center)	m	206.00	5,670.09	−0.518 <sup>a</sup>
T1:9	Distance to Sol (administrative center)	m	66.41	7,761.52	−0.506 <sup>a</sup>
T1:10	Minimum distance to the M-30 ring road	m	41.59	3,255.68	0.011
T1:11	Minimum distance to the M-40 ring road	m	2,309.83	7,031.65	0.456 <sup>a</sup>
T1:12	Distance to the nearest subway station	m	2.97	919.81	−0.491 <sup>a</sup>
T1:13	Distance to the nearest transport node	m	2.42	2,090.95	−0.591 <sup>a</sup>
T1:14	Distance to the nearest commuter network stop	m	15.78	2,759.95	−0.326 <sup>a</sup>
T1:15	Distance to the airport Adolfo Suárez—Madrid Barajas	m	6,524.73	14,357.13	0.164 <sup>a</sup>
T1:16	Distance to the nearest nightlife area	m	1.00	552.33	0.195 <sup>a</sup>
T1:17	Distance to the nearest service area	m	1.00	262.61	−0.388 <sup>a</sup>
T1:18	Distance to the nearest shopping center	m	11.40	2,054.56	−0.548 <sup>a</sup>
T1:19	Distance to the nearest hypermarket	m	54.78	5,138.69	0.192 <sup>a</sup>
T1:20	Distance to the nearest hospital	m	3.55	2,077.55	−0.228 <sup>a</sup>
T1:21	Population density	hab/km <sup>2</sup>	197.27	132,500.00	0.247 <sup>a</sup>

<sup>a</sup>Pearson's correlation coefficient statistically significant at 0.01 level.



**Fig. 3.** Map well-being index.



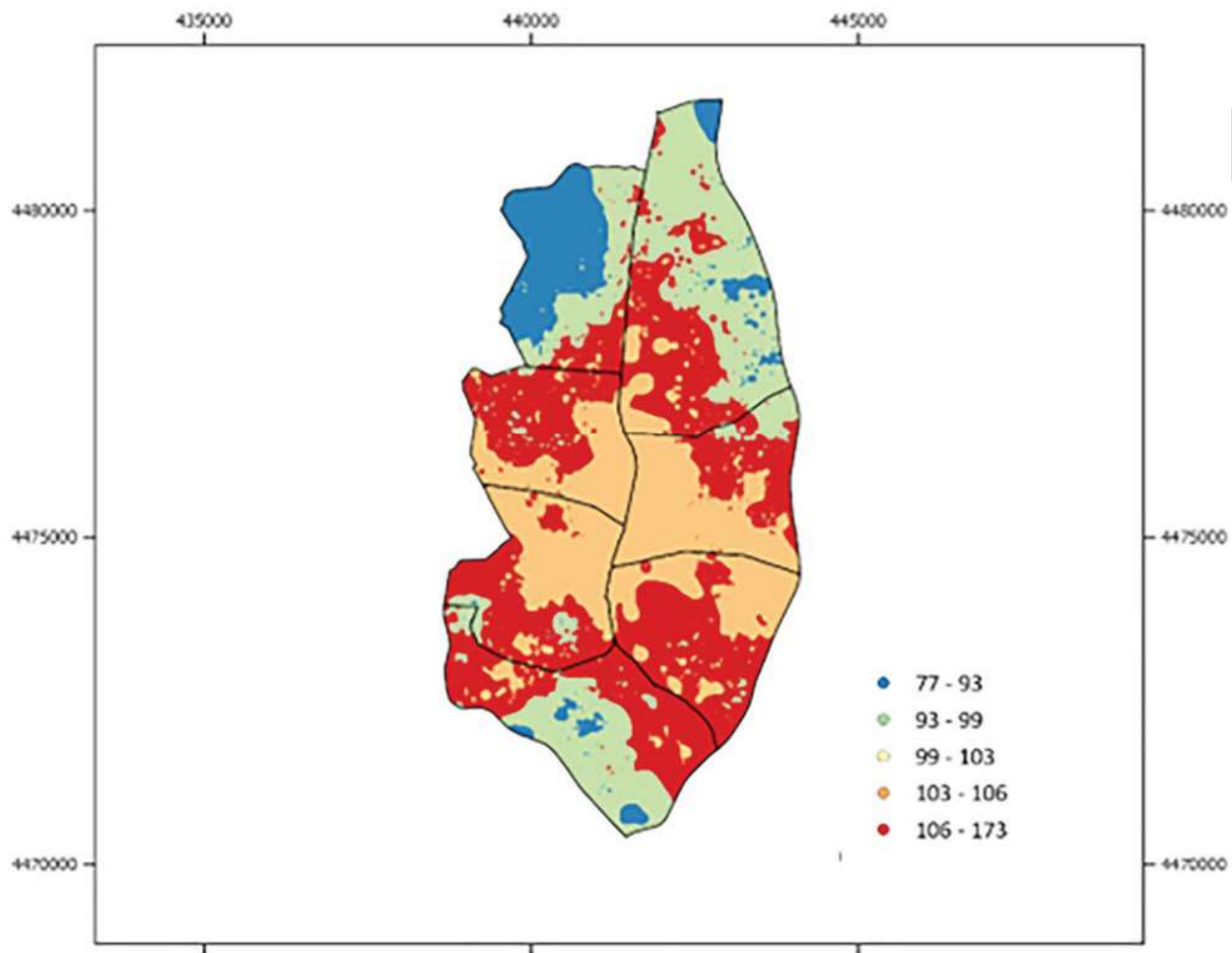


Fig. 4. Map well-being clusters.

Finally, and taking into account the administrative grouping of dwellings in districts, Fig. 5 shows the districts where the average level of well-being is above and below the mean, respectively.

As can be seen from the results in Table 1, in general, the distance to services variables correlates negatively with the well-being index, indicating that a greater distance to these services implies a lower level of well-being just as we expected. Exceptions are found for distances to the airport, nightlife, a hypermarket, and the ring roads. Regarding the distance to the ring roads, the sign obtained makes sense from the point of view of well-being since they are places with a high volume of traffic, which negatively influences the quality of life, as the negative sign of the traffic variable also indicates.

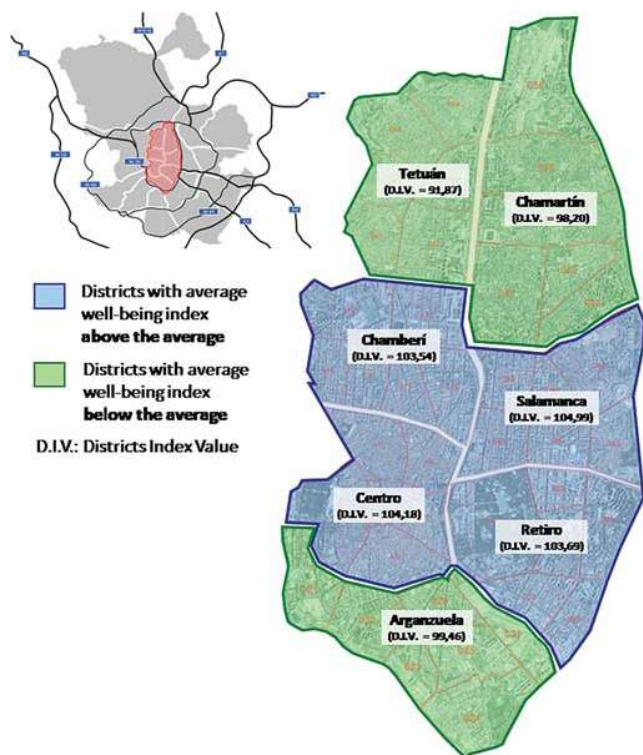
The positive and unexpected correlation between well-being and distance to a hypermarket could give a false idea that trade services do not positively influence well-being, however, the distance to a mall—which presents more and better commercial services—has the expected sign and one of the highest correlations. The price and the surface variables that are related to the quality of the dwelling are also positively related to its well-being value, as we expected.

On the other hand, a positive correlation is observed between the well-being and the variables of pollution and noise, which would indicate, not that these variables increase the quality of life of people, but rather that pollution and noise are usually

higher in the points best located with respect to basic services, that is, in places that we could consider as service centers of the central almond. Lastly, the data shows that greater proximity to the airport or leisure areas does not increase well-being levels.

From the results obtained for the housing well-being index represented in Fig. 3, it appears that the dwelling that is on the Castellana–Prado–Recoletos axis (identifiable through the vertical line that divides the central almond into two) present in general, higher well-being values, these homes are located mainly in the Chamberí, Salamanca and Centro districts according to Fig. 1. On the other hand, the highest concentration of dwellings with the lowest well-being index is found in the Tetuán district in the northwest of the central almond, where the majority of the dwellings register well-being values below the average level (100), specifically, for the most part, would have values lower than 93. The districts of Chamartín and Arganzuela also have a high number of dwellings with well-being below the average level.

The previous analysis is consistent with Fig. 4 of well-being clusters, where the central districts generally represent high levels of the well-being index while as indicated in Fig. 5 in the peripheral districts the levels of the index are lower, where it can be seen that the central districts register average values of the well-being index higher than the average value 100, while the peripheral ones have lower average values.



**Fig. 5.** Districts with an average well-being index above and below the average. (Base maps by Cartography Department Madrid City Council, Geportal.)

## Discussion

A large number of empirical studies relate the urban quality of life with a wide range of physical, social, and environmental characteristics, reaching similar results to those obtained in the present study. At the socioeconomic level, the study of the relationship between the price and the characteristics of the home is recurrent due to its relevance (Chasco and Sánchez 2012; Giannias 1998; Goerlich-Gisbert et al. 2019; Türksever and Atalik 2001; Zenker et al. 2013); but also between such characteristics of the house and the variables related to the provision of urban services such as the availability of sports facilities, provision of cultural services and museums (Banai and Rapino 2009; Clifton et al. 2008; Florida 2002; Ge and Hokao 2006; Glaeser et al. 2001; Insch and Florek 2010), availability of educational centers (Baum et al. 2010; Türksever and Atalik 2001; Zenker et al. 2013), access to health-care (Baum et al. 2010; Smith et al. 1997; Türksever and Atalik 2001; Zenker et al. 2013), access to stores for shopping (Banai and Rapino 2009; Clifton et al. 2008; Zenker and Rütter 2014), and to restaurants and nightlife (Florida 2002; Glaeser et al. 2001).

On the environmental level, the changes produced in cities by the high degree of urbanization have also led to the study of the link between the urban quality of life and air pollution (Chasco and Sánchez 2012; Giannias 1998; Graves 1976; Rosen 1979; Türksever and Atalik 2001; Zenker et al. 2013; Velázquez et al. 2019); noise (Baum et al. 2010; Chasco and Sánchez 2012; Türksever and Atalik 2001; Zenker et al. 2013), in particular the noise caused around airports (van Praag and Baarsma 2005); or the surface of green areas and the natural environment (Chasco and Sánchez 2012; Ge and Hokao 2006; Goerlich-Gisbert et al.

2019; Hoogerbrugge et al. 2021; Insch and Florek 2010; Velázquez et al. 2019).

The importance of the quality of life that travel time to the workplace has is also verified (*commuting*) (Ballas and Tranmer 2012; Goerlich-Gisbert et al. 2019; Stutzer and Frey 2007) and the accessibility and efficiency of public transport (Insch and Florek 2010; Marloes et al. 2021; Türksever and Atalik 2001). It is necessary to clarify that proximity to transport routes has been considered in two ways (Brereton et al. 2008), positively affecting well-being, when the degree of accessibility to it is captured (Banai and Rapino 2009; Goerlich-Gisbert et al. 2019; Želinský et al. 2021), or with a negative incidence, when negative externalities such as pollution and noise generated by the proximity of roads, railways, or airports predominate (Van Praag and Baarsma 2005).

The evidence that emerges from this study is in line with the different references cited, showing the importance of urban planning on the quality of life in large cities, so that a balance is achieved between greater accessibility to basic services demanded by the population and a significant reduction of acoustic and environmental pollution that has a negative impact on people's health.

## Conclusions

Starting in the second half of the 20th century, the most developed countries have experienced strong economic growth, as well as an intense process of population concentration, as the rate of urbanization of their population has increased significantly. These events have led to a significant decrease in air quality and an increase in noise, especially in urban centers. This reality, together with the population's level of accessibility to basic services and the quality of housing, has an impact on the well-being of the people who inhabit these centers. In this respect, this paper proposes a well-being index for dwellings in the central almond of Madrid—incorporating environmental variables such as pollution and noise and other elements such as proximity to basic services—that can help urban planners to take decisions to improve citizens' well-being. From the results obtained in the study for the case of a sample of dwellings in the central almond of the city of Madrid, it has been found that, in general, greater accessibility to transport, trade, and health services increase the levels of well-being. However, greater accessibility to leisure-related services does not have a positive impact on the levels of well-being. It has also been observed that noise and air pollution correlate positively with well-being against the expected result, which could be explained by the fact that pollution of both types is greater in places where homes are better located. Regarding basic services, the level of well-being provided by accessibility to these services is not significantly offset by the decrease in the quality of life of people being exposed to higher levels of contamination, which could be also related to the priorities and perception of the environmental quality by the city inhabitants (Chasco and Gallo 2013). Finally, it has been confirmed the hypothesis that the dwellings in the central districts of the central almond have higher levels of well-being than the peripheral districts. The results suggest, therefore, that from the point of view of the perception of well-being, a lower environmental quality does not significantly influence the decision of the population when establishing their place of residence so that the most polluted places are those that more population continue to accumulate, thus fueling the phenomenon of pollution. Therefore, the need to continue acting on these places with measures that curb the increase in pollution that objectively supposes a negative impact on the quality of life of the population is demonstrated. Also, a policy of decentralization of certain



553 services could bring higher levels of well-being to peripheral dis-  
554 tricts where noise and pollution are already lower.

## 555 Data Availability Statement

556 Some or all data, models, or codes that support the findings of this  
557 study are available from the corresponding author upon reasonable  
558 request.

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