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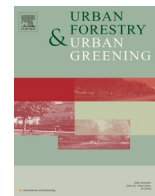
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Is compensation a myth? Modelling the use of public and private urban green spaces in relation to the geographical context

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ABSTRACT

The compensation hypothesis postulates that the absence of green spaces in residential areas leads to a greater use of public green spaces and nature in general. This paper tests this hypothesis by focusing on the use of public and private urban green spaces. A holistic approach is adopted that considers the complexity of residential context and the use of urban, peripheral and private green spaces. A survey was conducted in two medium-sized French cities (Dijon and Besançon) to identify how their green spaces were used and perceived. The residential context was described through multiple spatial and environmental metrics (physical and visual access to nature, noise level, private green space area) that were GIS-referenced to postal addresses. On the basis of that data, the compensation hypothesis was explored using a PLS path model. The results show the absence of compensatory behaviour when considering just the overall relationships between the use of different types of green spaces. However, conditional compensatory behaviours can be detected when allowance is made for other variables (physical and visual accessibility to nature, type of housing, dwelling floor area, noise level). These results remain dependent on the geographical context of the city, with a higher compensation effect where natural areas are less accessible.

1. Introduction

Green space (GS) is critical to making cities inhabitable. It provides a wide range of cultural ecosystem services, improving inhabitants' health (Kaplan, 2001; Keniger et al., 2013), well-being and cognitive abilities (Berman et al., 2008; Browning & Lee, 2017; Kaplan & Kaplan, 1989), reducing stress and fatigue (Kaplan, 1992; Sheets & Manzer, 1991), and fostering altruism and social relationships (Coley et al., 1997; Seeland et al., 2009; Weinstein et al., 2009). These benefits depend largely on the use made of GS, in particular the type and the diversity of activities practised there (O'Brien et al., 2017), and the frequency and duration of exposure to nature (Cox et al., 2017).

Definitions of GS vary across studies and are mostly broad and complex (Taylor & Hochuli, 2017). However, GSs are often considered as the set of more or less natural features, in contrast to artificial land cover, seeing that the beneficial experience of nature can be provided by a wide variety of natural environments, such as forests (Boulton et al.,

2018), agricultural spaces (Contesse et al., 2018; Triguero-Mas et al., 2015), blue spaces (Völker & Kistemann, 2011), private gardens, and spontaneous vegetation (Le Texier et al., 2018). Among these GSs, those used by urban dwellers are located within the city and on its outskirts (Schipperijn et al., 2010), may be either private or public (Cox et al., 2019) and of various types (Ibes, 2015).

Numerous studies have emphasised the use of public urban GSs, which are publicly managed and publicly accessible areas (Lachowycz & Jones, 2013). The preferred activity there is rest, fostered by facilities and biodiversity favouring a connection to nature (Kabisch & Haase, 2014; Wood et al., 2018). Public GSs also facilitate a wide range of free-of-charge or low-cost physical activities (Schipperijn et al., 2013; Ord et al., 2013) and are places for social interactions, especially near city centres (Ferrara et al., 2018). The same activity can be carried out in different types of green spaces, for example people may go jogging just as well in a large urban park as in a forest or even on a path crossing a field or meadows in the nearby periphery (Ives et al., 2017).

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Conversely, fewer studies consider the use of private GSs, which are usually defined as personal spaces attached to living spaces (e.g., gardens, backyards). Yet private GSs do not serve the same functions as public GSs (Bernardini & Irvine, 2007; Coolen & Meesters, 2012) and are seen as outdoor extensions of the home (Coolen & Meesters, 2012), contributing to their owners' overall well-being (Cervinka et al., 2016). Thus, home owners can do the gardening or relax much more easily, but to benefit from the social function or from access to specific sports facilities, they must go to a public GS (Ferrara et al., 2018). Certain activities (e.g., exercising) can be carried out in both a private garden or a public GS (Coolen & Meesters, 2012), although perhaps not equally as often.

Furthermore, other GSs do not fit into the public/private dichotomy, particularly cropland, non-state-owned forests and informal GSs located on the immediate periphery of cities. These peripheral GSs also have an impact on the quality of the urban environment (Ekkel & de Vries, 2017; Fan et al., 2017; Tyrväinen et al., 2007; Žlender & Ward Thompson, 2017), but quite how they differ from urban GS remains unclear (Wolff et al., 2020). Most studies of GS ignore peripheral spaces and confine their study areas to the administrative boundaries of cities. However, this does not necessarily correspond to people's actual experiences (Ekkel & de Vries, 2017).

Overall, the use of GSs depends on their characteristics, such as their size and the facilities they offer (Schindler et al., 2022; Schipperijn et al., 2010). The size of a GS generally defines its range of functions or the activities possible there (Stessens et al., 2017). But the geographical setting is also critical to GS use (Fish et al., 2016; O'Brien et al., 2017) and specifically their accessibility (Cohen-Cline et al., 2015) because of time constraints (Grahn & Stigsdotter, 2003). GS use also depends on socio-demographic and psychological factors. Older people tend to use GS more (Sang et al., 2016) as do people on high incomes (Oh et al., 2021) and dog owners (Schipperijn et al., 2010). Women tend to do more activities in GS than men (Sang et al., 2016). A connection to nature is also a motivation for using GS (Capaldi et al., 2014; Lin et al., 2014). This subjective factor may reflect the residential environment, considering the positive influence of greenery around the home on affinity with nature (Soga et al., 2015). More broadly, there are multiple interactions between socio-economic factors, attitudinal variables and the geographical context since, for example, the availability of urban GS and an affinity with nature impact residential choices in favour of individual housing and peripheral locations, suggesting a self-selection effect on GS use (Schindler et al., 2022; Maat & de Vries, 2006). This may explain why differences in accessibility to GS are observed according to the wealth level of neighbourhoods (Dai, 2011; Kabisch & Haase, 2014), leading to usage differentials in cities with high socio-ethnic segregation (Dai, 2011; Rigolon et al., 2018).

Among the many factors that jointly influence the use of GS, a major interaction has been defined as the compensation hypothesis. This states that the absence of greenery in the residential environment triggers compensatory behaviour, leading to more frequent use of public GS (Maat & de Vries, 2006). Several empirical studies have confirmed this hypothesis. Based on a literature review, Haaland & van den Bosch (2015) showed that living in a compact urban environment favours compensatory trips to natural areas. During the COVID-19 pandemic, public GS partly offset not having a private garden in protecting against the detrimental health effects of limited access to nature (Poortinga et al., 2021). A compensation process was also identified whereby not having private GS is related to a more intensive use of second homes (Byrne & Sipe, 2010; Holden & Norland, 2003; Strandell & Hall, 2015). Conversely, several studies have contradicted this hypothesis. Maat and De Vries (2006) and Grahn and Stigsdotter (2003) found that people living in houses with a garden tend to use public urban GS more often than flat-dwellers. Gidlöf-Gunnarsson & Öhrström (2007) did not observe any compensatory behaviour in the use of GS in relation to living in a noisy environment. However, it should be noted that the studies refuting the compensation hypothesis took segmented

approaches, either by leaving out characteristics of the dweller's urban environment that might be instrumental in the compensation equation, or by adopting an overly restrictive definition of GS.

This article tests the compensation hypothesis by examining the use of GS while allowing for the geographical context. We assume that compensatory behaviour is complex to detect and involves going beyond a mere comparison between the use of public GS and the ownership of a private GS. Thus, this article revisits the compensation hypothesis using a holistic approach: (i) by considering all the types of green space that can be found in an urban environment and its close periphery; (ii) by taking into account the characteristics and the perception of the geographical context of individuals, i.e. their home characteristics, their visual accessibility to nature, their functional accessibility to GS, and their exposure to noise. We hypothesise that specific forms of compensation in terms of practices may be identified by considering all the GSs, functional and visual access to GSs and residential quality. To strengthen our results, we compare two cities in the same region, namely Dijon and Besançon, using the same methodological approach.

2. Data and methods

2.1. Study sites

The two cities under study are the main urban agglomerations of the Bourgogne-Franche-Comté region. Dijon is the regional capital and the most populous urban centre with 158,000 inhabitants within the municipal area and about 90,000 inhabitants in the suburban area. Besançon is the region's second largest urban centre with 118,000 inhabitants in the municipality and about 22,000 inhabitants in the suburbs. Although Dijon is a larger city, both have similar functions dominated by service sectors, each including for example a medium-sized university. Consequently, their populations are similarly composed. As concerns landscape, both cities are located beside plateaus but their sites differ in the sharpness of the relief. Dijon lies to the east of the plateau of Burgundy, below a 100-m wooded escarpment, and extends over a large arable plain, while Besançon is located at the western edge of the Jura plateau, where elevation rises from 240 to 600 m and where the River Doubs meanders around steep wooded hills.

2.2. Geographical data

For each city, several geographical sources were combined to create a land cover map of the urban agglomeration and its rural environment (Fig. 1). Buildings, roads, railways, waterbodies and the main wooded areas were extracted from the French National Geographical Institute database (BD-TOPO). Croplands and grasslands were provided by a French agricultural database (Graphic Plot Register). Within the urban fabric, wooded and herbaceous areas were obtained from a classification combining satellite images (Pleiades sensors at 50 cm resolution) and a digital surface model derived from Lidar imagery. All these sources were harmonised to produce a 1 m-resolution map with 37 land cover categories.

2.3. GS identification

GSs considered in this study were located in the cities and their immediate outskirts, i.e. up to a network distance of 5000 m from the municipal boundaries, allowing us to include 90 % of the home-public GS distances recorded in the survey (see below). GSs located beyond 5000 m were deemed to belong to rural areas and so omitted from the analysis.

Following the generic definition of GSs as natural spaces (Taylor & Hochuli, 2017), to avoid excluding any form of use and to take into account the diversity of GSs used for the same activity, we used the land cover map to select all areas of forest, grassland, herbaceous cover, cropland and water bodies within the urban areas previously defined.

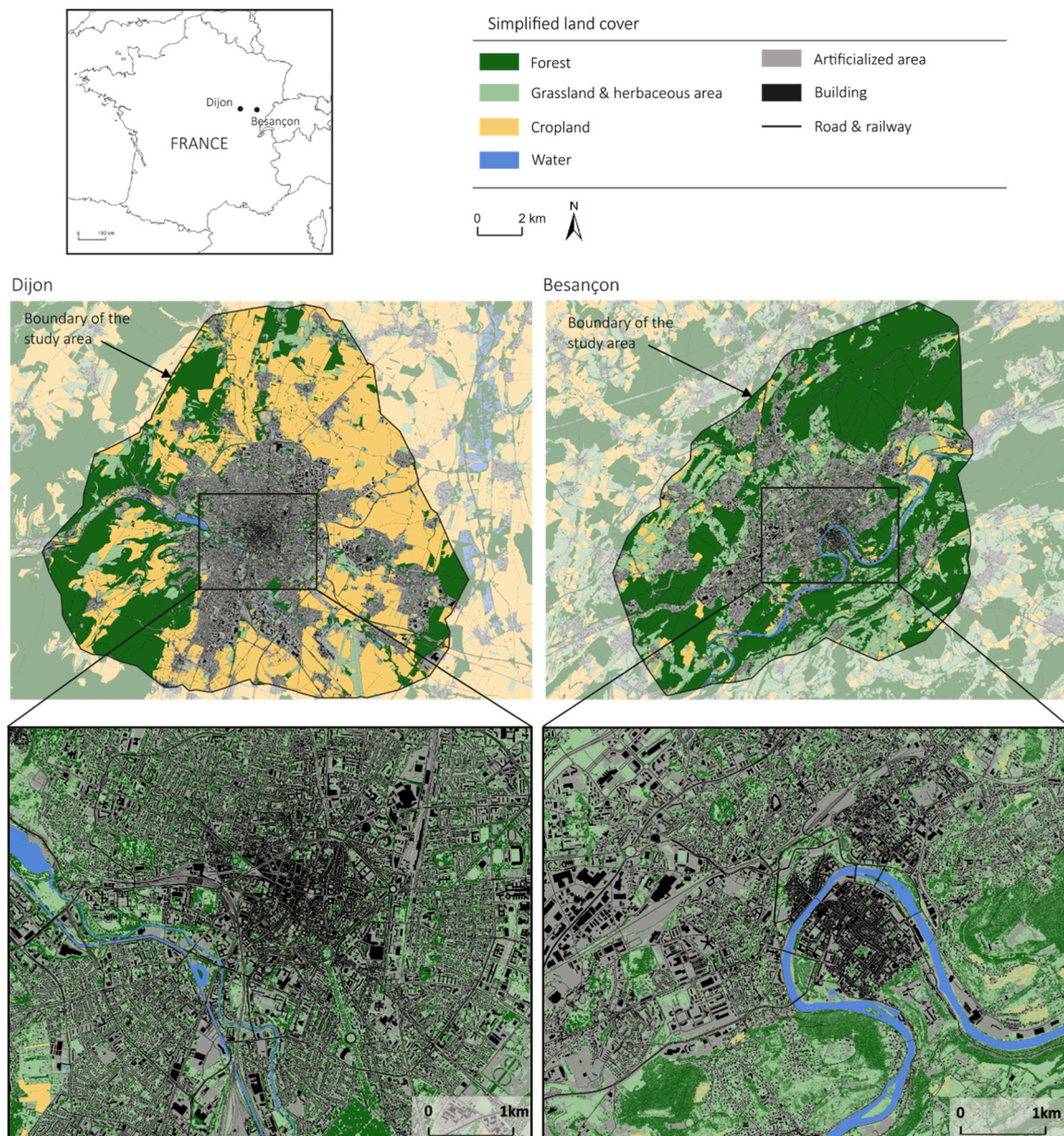


Fig. 1. Land cover in the study area of Dijon and Besançon on two scales (city and city centre).

We also considered the GSs defined by the municipalities of Dijon and Besançon, and like Boulton et al. (2018), we selected those forming vegetated urban land such as parks, natural and built corridors adjacent to waterways, vegetated areas of street and road corridors, sports fields, and cemeteries. From this whole set of GSs, we removed areas of less than 10 m^2 , e.g. strips of grass. Then, three categories of GS were defined from two criteria. A first criterion was used to distinguish between urban and peripheral green spaces, according to their location inside or outside the urban core. The core boundary was defined using Morpholim software, a tool based on fractal geometry (Tannier & Thomas, 2013). A second criterion was used to separate public and private GS in the urban area by combining municipality databases of GS defined as publicly accessible and the IGN plots database. GSs with admission charges were omitted because there is only one in the two towns studied (Besançon Zoo). As a result, we considered (1) public urban GS (PUGS), (2) private urban GS (PRGS), and (3) peripheral GS (PEGS).

2.4. Face-to-face and online survey

A survey was carried out simultaneously in the cities of Dijon and Besançon to evaluate individuals' use and perception of private and public GS. In total, 966 valid questionnaires were collected during October and November 2021: 73.7 % were administered face-to-face, on the street, and outside GSs so as not to target users only; 29.3 % were administered online, through leafletting (in residential areas), posters in public places and a media campaign. The samples are divided equally between the two cities (487 in Dijon and 479 in Besançon). Each respondent was GIS-referenced based on the postal address. The proportions of responses reflect quite accurately the age pyramid for both cities: the maximum difference is +6.7 % for 18–27 year olds in Dijon and –5.0 % for 65–79 year olds in Besançon (Table 1). The response rates by district are fairly closely matched with the population level by district (Table 1). The maximum difference is +7.3 % at Chevreur-Parc (Dijon) and +8.5 % at Centre-Chapelle-des-Buis (Besançon), which are central districts. The minimum difference is –4.7 % at Montchapel

(Dijon), which is a residential district of detached housing, and -4.9% at Châteaufarine-Planoise (Besançon), which is an outlying residential district with collective housing. An under-representation of lower socio-occupational categories (-9.8% for the unemployed in Dijon and -13.1% in Besançon) and an over-representation of students ($+12.5\%$ in Dijon and $+5.2\%$ in Besançon) can be noted for both cities (Table 1). Women are also more strongly represented (56.3% in Dijon and 55.3% in Besançon).

The survey is arranged into six parts. Part 1 draws profiles of GS users and their affinity with nature using Likert scales. Part 2 concerns the uses of urban and peripheral public GSs. We first asked respondents about the different types of GSs commonly used in a year from a long list of GSs consistent with above definitions. We then asked them to name or locate on a map the three public GSs that they frequented most, then to specify their usage habits in each of them (activities, preferences, frequency, and period of use). Part 3 is like the previous one but for private GS. Part 4 evaluates the perception of the view of nature from home. Part 5 characterises the place of residence (floor area, number of occupants, facilities). Finally, Part 6 provides a profile of respondents: age, gender, socio-occupational category, educational qualifications, pet ownership. Following this survey, a few green spaces declared by the respondents were removed from the analyses because they were non-vegetated spaces.

2.5. Modelling individuals' residential environments

2.5.1. Gravity accessibility to public GSs

We used a gravity model to measure a potential of accessibility to public GSs. As in many studies based on a gravity accessibility approach (Chen et al., 2020; Dai, 2011; Luo & Wang, 2003; Zhang et al., 2017), we considered that the attractiveness of a GS is related to its size. However, four types of green spaces were removed from the calculation of accessibility metrics because there were used very little by the respondents and because the gravity logic was less suited to these spaces. These are sports fields and cemeteries in the PUGS category, and fields and meadows in the PEGS category. Therefore, only forest areas were taken into account for calculating gravity accessibility to PEGS.

There is no empirical support for determining the maximum distance of GS use from the place of residence (Ekkel & de Vries, 2017; Schindler et al., 2022). Consequently, we created three metrics for assessing the accessibility from the home to any public GS. Considering the set of entrance points to a GS (i.e., intersection points between the paths into the GS and the GS boundaries), we computed the shortest network distance from the home. We then arranged them into three classes (500 m, 2000 m and 5000 m away), in a similar way to Jalkanen et al. (2020). For each individual surveyed i , the generalised accessibility (GA_i) was calculated as follows for the three distances considered:

$$GA_i = \sum_{j=1}^n \frac{M_j}{d_{ij}^\alpha}$$

where:

- d_{ij} is the shortest network distance (metres) between the respondent's home i and the GS j ;
- α is the coefficient of friction of the distance. We chose a neutral coefficient of friction ($\alpha = 1$) because values greater than 1 give a negligible accessibility measure in the model and the survey showed that large peripheral GSs are often visited.
- M_j is the attractiveness potential, i.e. the area for PUGS (m^2) and the forest area for PEGS (m^2).

2.5.2. Visual access to nature

Little research has been done on the complementarity between visual and functional access to nature. Indices quantifying the visibility of nature through aerial images (NDVI) are of limited use because the

proportion of nature visible from the sky does not correspond to the proportion of nature visible for an observer at ground level (Labib et al., 2021). Consequently, we used a modelling approach for visibility evaluating, for each individual surveyed, the average proportion of nature visible from their home and the average range of view. We used the PixScape application software based on 2D $\frac{1}{2}$ calculations (Sahraoui et al., 2018). The input data were a digital terrain model and a digital surface model derived from a LIDAR image, combined with a land cover map at a resolution of 1 m. Having collected the individual's address, floor, and direction of view (towards the courtyard, towards the street, or both), we were able to model the visibility indicators from the different facades of the building and then average them.

2.5.3. Noise exposure

Noise level was calculated according to the European Commission's Environmental Noise Directive 2002/49/CE using the MITHRA-SIG v.5.4.1 noise-prediction software application developed by Geomod and the French Scientific and Technical Centre for Building (CSTB). Three types of noise sources were considered: road traffic, rail traffic and foot traffic in pedestrian streets. Topographic data including buildings, roads, and railways (from the French National Geographical Institute database, BD TOPO 2016), meteorological data (from French National Meteorological Service), and traffic data for each rail and road section were integrated in the model.

A noise map was calculated in a 1×1 m raster grid covering the study area. The noise metric was based on the annual outdoor equivalent continuous A-weighted sound levels (L_{Aeq} , in dB) during the day (L_{Day} 06:00–18:00). The noise exposure level was calculated at the front of each building by selecting all the pixels surrounding the building between 0 and 2 m from the façade and then calculating the logarithmic average of the selected pixel value. Noise exposure at home was defined by the average daily noise level in front of the building.

2.6. Statistical analysis

We first carried out Wilcoxon tests to detect significant differences between the cities of Besançon and Dijon in terms of daily contact with nature and the importance of nature for individuals. We then proceeded to the global model. Given the complex causal relationships to be analysed, we opted to use a form of latent variable structural equation modelling known as Partial Least Square Path Modelling (PLS-PM). PLS-PM can estimate complex causal relationships between latent variables, i.e. variables not directly measured but constructed from measured manifest variables (Sanchez, 2013). We then performed two resampling methods using bootstrap t-tests (Sanchez, 2013) to check whether the study area (Dijon or Besançon) and the type of habitat (house or flat) influenced the general model.

The model has 14 latent variables: 4 variables of interest and 10 explanatory variables (see appendix 1 for the construction of these variables). Manifest variables were grouped for shaping latent variables when similar in meaning and when their loading was greater than 0.7, as recommended by Sanchez (2013) (appendix 1).

The variables of interest are: the intensity of use of PUGS; the intensity of use of PEGS; the diversity of use of public GS (PUGS and PEGS); the intensity and diversity of use of PRGS. The intensity of use corresponds to the frequency of use of GSs over time and to the total number of activities carried out. The diversity of use corresponds to the number of different activities carried out in the GS and the number of different types of public GS frequented (park, square, cemetery, sports complex, tree-lined walk, forest, cropland, water body). The 10 explanatory variables are arranged into four topics:

- > the dwelling context (5 variables): landscape satisfaction, view of nature, landscape openness, floor area, and building noise exposure;
- > the gravity accessibility potential (2 variables): PUGS accessibility and PEGS accessibility;

- > the area of PRGS (1 variable);
- > the subjective relationship with nature (2 variables): affinity with nature, interaction with nature.

We explored the relationships between each explanatory variable and the variables of interest as well as between the variables of interest themselves (44 relationships).

3. Results

We first describe the global characterisation of the usage of GS (Section 3.1.). We then explore the compensation hypothesis by presenting the PLS-PM general model (Section 3.2.) and finally we describe the influence of the study area and the type of habitat on this model.

3.1. Overall characterisation of the use of green space

In all, 79.8 % of individuals use urban GS at least three times a year. They frequent mostly urban parks (83.9 %), blue spaces such as river banks or lakes (60.6 %) and peripheral forests (55.6 %), followed by urban squares (38.7 %), cropland (31.4 %), sports complexes (9.5 %) and cemeteries (8.7 %). A wide variety of activities are carried out with, on average, more than four different activities per person. The most frequent activities include walking (70.6 %), being out in a natural setting (63.2 %), being with family and friends (59.3 %), playing sports (47.3 %) and relaxing (45.4 %). Of the 61.4 % of people using a private GS, most have a garden at home (59.0 %) or use their friends' or family's space (56.7 %). Few use shared or community allotments (6.6 %).

The use of GS differs between the two cities studied. The affinity with nature scored on a scale from 0 to 5 is significantly higher for Besançon residents (3.50) than for Dijon residents (2.96; $p < 0.001$), as is daily contact with nature (4.35 for Besançon; 3.69 for Dijon; $p < 0.001$). This difference can also be seen in people's practices with respect to green spaces: 35.7 % of Dijon residents do not use urban GS, compared with just 0.8 % in Besançon. The activities carried out are also more diversified on average in Besançon ($n = 4.5$) than in Dijon ($n = 3.6$).

Another difference between the two cities is the spatial distribution of the GSs visited (Fig. 2). In Besançon, the most visited GSs are concentrated in the city centre where most of the urban parks are located, as well as the banks of the River Doubs and some peripheral forests that are easily accessible from the city centre. The peripheral Chailluz forest, to the north, is also one of the most popular GSs. In Dijon, the frequentation density shows a more homogeneous spatial distribution. Around this city, peripheral GSs (cropland and forests) are also less visited (Fig. 1). The median distance between the place of residence and the GS frequented by the individuals surveyed is 1421 m in Besançon and 1690 m in Dijon. When considering all potential GSs, the average distance between the individuals surveyed and urban GS is 3101 m in Besançon and 5863 m in Dijon; for peripheral GS, it is 4774 m in Besançon whereas it is 6255 m in Dijon. Thus, the accessibility of GS is better overall in Besançon than in Dijon.

3.2. Mixed results for the compensation hypothesis

In order to explore the compensation hypothesis, the PLS-PM model is used to perform two analyses: (1) the first concerns the influence of the characteristics and the perception of the geographical context on the intensity and diversity of use of GS (Figs. 3a, 3b, 3c, 3d); (2) the second concerns the influence of the use of each type of GS (variable of interest) on the use of the other ones (Fig. 3e). Complementary analyses of the relationships between certain explanatory variables are presented in order to complete the holistic approach (Fig. 3f).

As seen in Fig. 3, all the explanatory variables have, in one or more instances, a significant effect on the variables of interest but that varies with the type of the GS considered. Thus, affinity and interaction with nature have a positive and statistically significant effect on intensity of

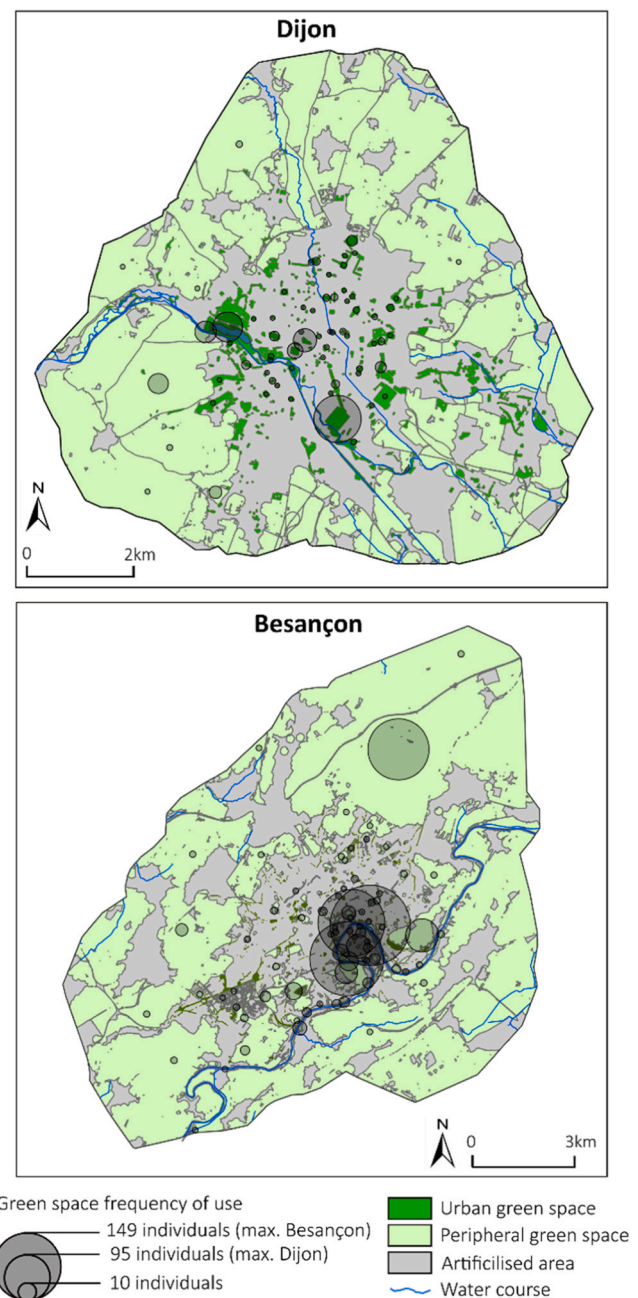


Fig. 2. GS frequency of use in Dijon ($n = 515$) and Besançon ($n = 949$).

the use of PUGS (Fig. 3a). Surprisingly, the accessibility variables have no influence on this variable, whereas the surface area of PRGS has a negative but small effect. The intensity of use of PUGS also depends on the residential context, with view of nature having a negative effect and both satisfaction with landscape and noise exposure a positive effect.

As with PUGS, affinity and interaction with nature have a positive effect on the intensity of use of PEGS (Fig. 3b). However, the dwelling context does not have the same influence since dwelling floor area has a positive effect while the metrics used to model the landscape seen from home are not significant. Conversely, access to PEGS has a positive impact on their intensity of use whereas access to PUGS has a negative impact.

The intensity and diversity of use of PRGS is influenced by the affinity with nature again, unlike interaction with nature (Fig. 3c). The graph illustrates that several variables related to the dwelling context are associated with this variable of interest, but in contrast to the use of

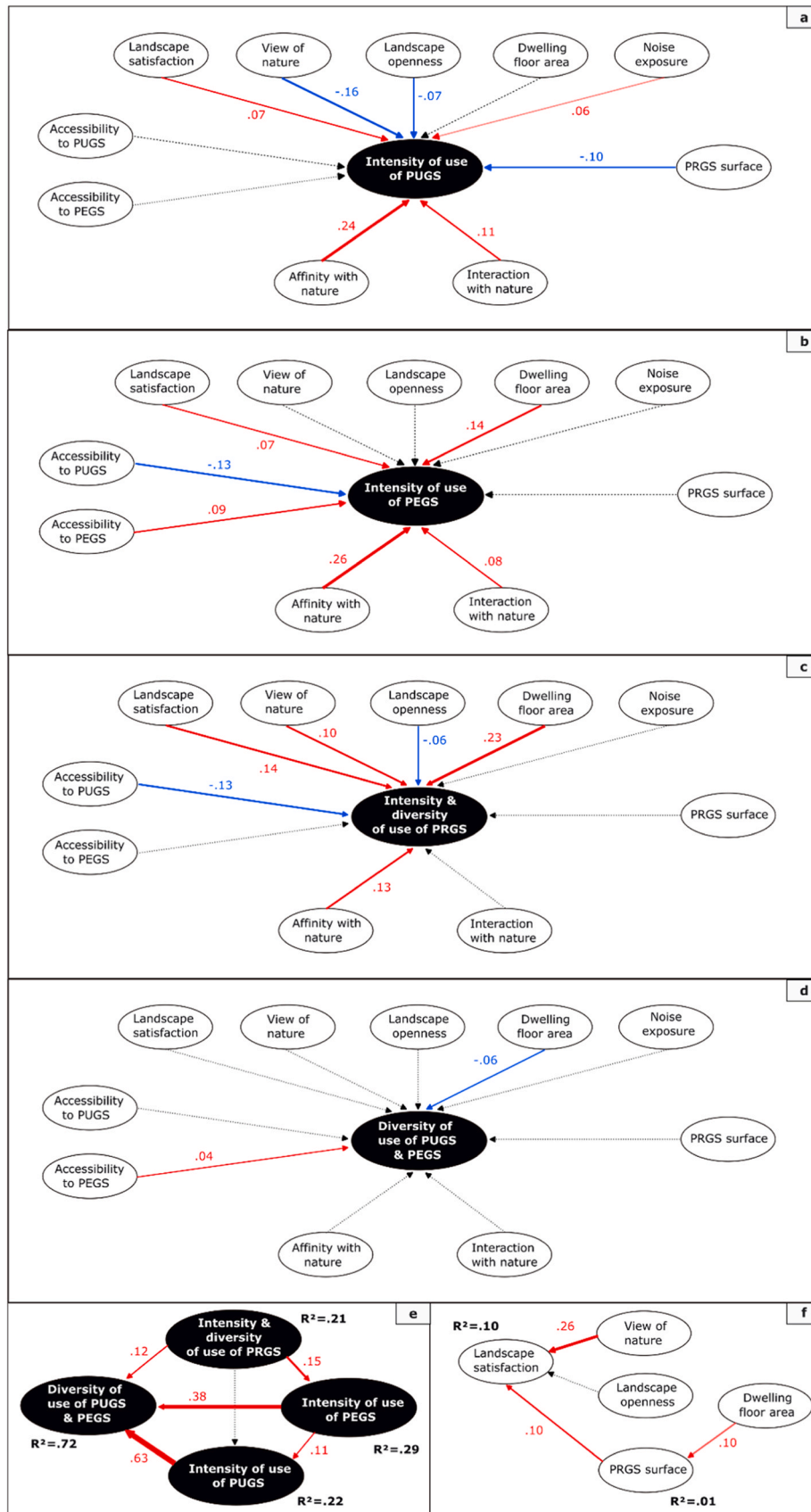


Fig. 3. Partial Least Square Path-Modelling of the intensity and diversity of use of green spaces for the cities of Dijon and Besançon (it is a single and unique model whose graphical representation is sequenced according to the variables of interest taken one by one (a, b, c, d), taken together (e), and the relationships between certain explanatory variables (f)).

PUGS, the view of nature has a positive influence here. Additionally, as expected, accessibility to PUGS is low when the intensity and diversity of PRGS usage is high.

A complementary analysis considers the diversity of the use of both PUGS and PEGS (Fig. 3d). Unlike for the previous variables of interest, few explanatory variables have any influence and the intensity of the relationships is very low. However, as expected, it is associated with accessibility metrics, but only for PEGS.

When considering the relationships among the variables of interest (Fig. 3e), the intensity of use of PUGS and intensity of use of PEGS are positively correlated with the diversity of their use, in a logical way. Although the intensity and the diversity of use of PRGS does not influence the intensity of use of PUGS, it does have a positive impact on the intensity of use of PEGS and on the diversity of use of both PUGS and PEGS. In the same way, the intensity of use of PEGS is high when the intensity of use of PUGS is high.



Fig. 4. Resampling of the global model to observe differences according to the city of residence (Dijon or Besançon) or the type of residence (house or flat).

Finally, among the relationships between explanatory variables (Fig. 3f), the dwelling floor area has a positive impact on PRGS area, and the view of nature and the PRGS area have a positive impact on landscape satisfaction. However, landscape openness has no significant influence on landscape satisfaction.

3.3. Exploring structural effects

Exploring structural effects reveals substantial differences depending on the city of residence or type of dwelling (Fig. 4). The application of the resampling method according to the city shows that in Besançon, the intensity of use of PUGS is mainly driven by accessibility of PUGS and affinity with nature, but not by the interaction with nature or the dwelling context (Fig. 4a). It should be noted that accessibility of PUGS had no influence in the general model whereas it has here a positive and significant influence. In Dijon, the intensity of use of PUGS is positively linked to affinity with nature, interaction with nature and noise exposure, whereas having a view of nature has a negative impact. The type of dwelling is more discriminating in the intensity of use of PUGS (Fig. 4a). People living in collective housing (flats) use PUGS more intensively when they have an affinity with nature, regular interaction with nature, more floor area, better access to PEGS and when they have greater landscape satisfaction, whereas these variables are not significant for people living in detached housing (houses). Conversely, they use PUGS less intensively when they have less open landscapes and less of a view of nature, whereas people living in detached housing use PUGS less intensively when they have ready access to PRGS.

Accessibility to PEGS and the interaction with nature explain the intensity of use of PEGS in Dijon but not in Besançon (Fig. 4b). The negative relationship between accessibility of PUGS and the intensity of use of PEGS identified in the general model is also significant here whatever the type of housing, but it is no longer significant when considering each city separately. Landscape openness has a positive impact on the intensity of use of PEGS for people living in detached housing only. On the contrary, people living in flats use PEGS more intensively when they have good accessibility to PEGS, a strong interaction with nature and extensive dwelling floor area. Affinity with nature has an influence whatever the residential context, but it is more intense for people living in houses.

Landscape satisfaction and affinity with nature explain the intensity and diversity of use of PRGS in Dijon (as in the first model) but not in Besançon (Fig. 4c). In Dijon, landscape openness is not linked to more frequent and diversified PRGS use whereas in Besançon this variable has a negative impact. Dwelling size and noise level positively impact the intensity and diversity of use of PRGS for people living in houses, while these two variables have no significant effect for people living in flats. As in the general model, accessibility to PUGS has a negative influence on the intensity and diversity of use of PRGS, but only for people living in flats.

In Dijon, no variable significantly affects the diversity of use of PUGS and PEGS whereas in Besançon, accessibility to PEGS has a positive impact while interaction with nature and dwelling floor area have a negative influence on the diversity of use of PUGS and PEGS (Fig. 4d). Moreover, accessibility to PEGS has a positive impact on this variable but only for people living in houses.

Lastly, exploring the structural effects among the variables of interest reveals a major difference (Fig. 4e). In particular, we note that in the general model, the intensity of use of PEGS has a positive effect on the intensity of use of PUGS, but with contrasting results for the different cities since the relationship is positive for Dijon but negative for Besançon.

4. Discussion

In this paper, the compensation hypothesis is explored through two complementary analyses. The first concerns interactions between

variables relating to the use of the different types of GS whereas the second addresses the influence of the characteristics and the perception of the geographical context on the intensity and diversity of use of GS. The results of the first analysis fail to confirm the compensation hypothesis. The intensity of use of PRGS is associated with more intense use of PEGS and more diversified activities in both types of public green spaces. Similarly, the more PEGS are used, the more PUGS are used, leading also to greater diversity in activities carried out and the types of GS frequented. These results are consistent with previous studies which found that the lack of access to a private garden does not lead to greater use of public GS (Grahn & Stigsdotter, 2003; Maat and de Vries, 2006) and that public GS cannot be a substitute for private GS (Bernardini & Irvine, 2007; Coolen & Meesters, 2012). Our results also confirm that PEGS and PUGS do not fulfil the same functions and that PEGS contribute to the quality of life as suggested by various studies (Ekkel & de Vries, 2017; Fan et al., 2017; Žlender & Ward Thompson, 2017).

However, when we include variables defining the geographical context of individual's residence, several results point to compensatory behaviour. First, having poor access to PUGS increases the intensity of use of PEGS whatever the type of housing. This result is consistent with the study of Schindler et al. (2018) which demonstrated that local under-provision of UGS increases distance travelled in keeping with a logic of compensation. This result may also reflect a spatial structuring effect, i.e., a residential location in low-density peripheral districts with poorer access to PUGS but better access to PEGS, which may explain why house dwellers are more concerned by this type of compensation. Second, not having or having a small PRGS surface area influences the use of PUGS for people living in house. Poortinga et al. (2021) report similar results for the first lockdown due to Covid-19. However, this result is in disagreement with other studies that do not consider the surface of PRGS, but the presence/absence of gardens, their quality or their proportion at the neighbourhood scale (Lategan & Cilliers, 2016; Coolen & Meesters, 2012; Maat & De Vries, 2006). But these studies were conducted before the Covid-19 epidemic lockdown, an experience which may have changed the way urban populations use natural areas, at least in the medium term. Third, the lack of visual access to nature and the limited openness of the landscape increases PUGS use. To our knowledge, this is the first time that such relationships have been demonstrated using both accessibility and visual metrics. Fourth, people living in noisy environments tend to use PUGS more often, which is consistent with other results showing that interactions with GS reduce noise sensitivity and noise annoyance (Dzhambov & Dimitrova, 2015; Van Renterghem, 2019). Fifth, people living in dwellings with little floor area make more diversified use of PUGS and PEGS. This is also a new result insofar as other studies make the link between urban densities and urban GS use rather than looking at the individual level (Bertram & Rehdanz, 2015; Chen et al., 2020; Schindler et al., 2022; Stessens et al., 2017). Sixth, people who have limited access to PUGS use PRGS more frequently and for more diverse usages. For those people, some of the activities carried out in the PRGS could therefore be transferred to PUGS if they were easily accessible, which partly contradicts the assertion that public GS and private GS do not have the same functions (Bernardini & Irvine, 2007). Thus, rather than a general compensation that could be valid for all the uses of PUGS, our analyses show different forms of "conditional compensation" that may be revealed only when integrating all the variables involved in this multidimensional phenomenon. This confirms the key-role of the residential geographical context of individuals in their use of GS.

These points in favour of the compensation phenomenon must, however, be nuanced. The relationship in favour of the compensation hypothesis only holds between variables describing residential context and use of PUGS, while the use of PEGS does not seem to be based on any compensatory logic. In addition, the intensity and significance of the relationships between residential context variables and use of GS depends on the city context. As an example, dwelling noise level and visual access to nature have a negative impact on PUGS use, but only for

inhabitants of Dijon. In Besançon, people tend to offset their lower interaction with nature in their daily lives by a more diversified use of PUGS and PEGS. Besides, compensatory behaviour proves to be more apparent in Dijon than in Besançon. Since these cities are of comparable size, we can interpret this difference in the light of their surrounding landscape. Besançon's urban fabric is mainly located in the immediate vicinity of wooded PEGS (hills, outer Jura plateau, Doubs riparian zone) whereas a large part of Dijon's PEGS are cropland (to the east) or not directly accessible from the city-centre (to the west). This difference in access to greenery may explain the greater need felt by inhabitants of Dijon to seek out nature when their residential environment is noisy or does not afford a view of nature. Furthermore, the difference in overall use of GS between Besançon and Dijon is quite marked and may be explained by this landscape context. It seems that the more access a city provides to nature (wooded areas in the periphery of the city, waterways, etc.), the more people frequent GS and have more interaction and affinity with nature. This also explains why accessibility to PEGS plays a critical role in Dijon only, where provision of peripheral wooded areas and waterways is lower overall than in Besançon. Thus, it remains difficult to identify systematic variation independently of the city context as suggested by Schindler et al. (2022).

Several perception factors partly explain the absence of certain compensation phenomena. Affinity with nature and regular interaction with nature are both strong predictors of the use of GS, whether urban or peripheral, which is in line with the results of Capaldi et al. (2014) and Lin et al. (2014). This may explain the positive correlation in the use of PRGS with other types of GS, and thus the absence of an overall compensation phenomenon. Furthermore, if the positive relationship between affinity with nature and use of PRGS is significant whatever the type of dwelling, it is nevertheless stronger for the inhabitants of houses. This corroborates the self-selection effect mentioned by Maat and de Vries (2006), Spielman & Logan (2013) and Schindler et al. (2018; 2022), where availability of urban GS and affinity with nature impact residential choices in favour of detached housing and peripheral locations, which in turn impact the frequency of use of PRGS and PEGS. Thus, it may explain why accessibility to PUGS does not influence its use in the general model while affinity with nature has a strong effect, in line with studies by Lin et al. (2014) and Schindler et al. (2022) but in contradiction with others (Coombes et al., 2010; Grahn & Stigsdotter, 2003; Neuvonen et al., 2007). Nevertheless, access to PUGS has a significant influence on the use of PUGS in Besançon, nuancing this apparent contradiction. The gravity accessibility metrics, used here to identify the influence of a global potential of accessibility, are probably more sensitive than other metrics to the spatial configuration of the city. Indeed, Besançon is characterized by the presence of many large green spaces located along the River Doubs and near the city centre, favouring their intense and frequent use by residents of nearby neighbourhoods, as seen in Fig. 2. Dijon has fewer large urban green spaces and the largest of them, the Colombière park, is located in a very residential and low-density neighbourhood in the south of the city. Other individual factors may explain the use of GS and the compensation phenomena such as age, gender, income level, etc. (Oh et al., 2021; Sang et al., 2016). To gain insight into the overlap between individual and contextual factors, complementary analyses might be considered.

In addition, other contextual variables could have been included in the analysis. Physical barriers (e.g. major roads, noise, safety, etc.) may have an impact on GS use (Giles-Corti et al., 2005). Thus, the quality of GS, which can be defined by multiple criteria such as facilities, noise level, cleanliness, security, natural quality, etc. (Stessens et al., 2020), influences the intensity and diversity of GS use (Ferrara et al., 2018; Francis et al., 2012; Schindler et al., 2022) and indirectly has a positive impact on health and stress levels (Francis et al., 2012; Honold et al.,

2016). Besides, there are many ways of modelling the green space quality mentioned in the scientific literature based on spatial metrics (Fan et al., 2017; Stessens et al., 2020). This is an important issue insofar as the quality of GS is a subjective notion and varies with the type of GS (Wood et al., 2018). By adding other types of accessibility metrics and combining all the spatial metrics used in the PLS-MS model and urban GS quality metrics, it would be possible to refine the results and better understand GS visitor choices.

5. Conclusion

Through a face-to-face and online survey and statistical modelling of the use of green spaces in two medium-sized cities, this article has shown that compensatory behaviours are detectable only when considering the type of green spaces (urban, peripheral, private), the multiple interactions between individuals and green spaces, and the residential context of individuals. Although the compensation phenomenon does not arise when observing the overall relationship among different types of green spaces in terms of intensity of use, conditional compensatory behaviours can be detected when allowance is made for physical and visual accessibility, dwelling floor area and environmental noise. In particular, low accessibility to private green spaces, low visual accessibility to nature and a noisy residential environment positively affects the intensity of use of urban green spaces. The results vary with the geographical context of the city, the compensation effect being greater when nature is less accessible.

Author Statement

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CRedit authorship contribution statement

Frédéric Mauny: Project administration. **Emeline Comby:** Writing – review & editing, Conceptualization. **Jean-Christophe Foltête:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision. **Hélène Houot:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Esteban Bopp:** Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Investigation, Formal analysis, Data curation. **Sophie Pujol:** Writing – review & editing, Software. **Gilles Vuidel:** Software, Data curation. **Nadine Bernard:** Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix

Table 1
Descriptive statistic of survey responses for each city

	Dijon (n=487)	Besançon (n=479)
Face-to-face response	452	262
Online response	37	219
Gender (%)		
Female	55.3	56.3
Male	43.8	43.7
Non-binary	0.8	0.0
Age (years) – deviation (%) from the Dijon and Besançon population		
18–24	+6.7	–0.4
25–39	+1.3	+2.3
40–54	–1.1	+0.2
55–64	–3.1	+2.8
65–79	–3.6	–5.0
80+	–0.1	+0.4
Socio-occupational categories – deviation (%) from the Dijon and Besançon population		
Farmers	0	0
Small business owners	+5.7	–0.2
Executives	+0.1	+9.9
Intermediate professions	–3.6	–2.6
Clerical workers	+3.8	+9.8
Manual workers	–5.8	–7.8
Retired	–2.9	–1.2
Unemployed	–9.8	–13.1
Students	+12.5	+5.2
Districts – maximum deviation from the population rates of the Dijon and Besançon districts		
Under-representation	–4.7 % (Montchapet)	–4.9 % (Chateaufarine-Planoise)
Over-representation	+7.3 % (Chevreul-Parc)	+8.5 % (Centre-Chap.-des-buis)

Table 2
Detail of the construction of the latent variables of the global model

Latent variable	Manifest variable	Loadings	Type of variable	Provenance
Intensity of use of PUGS	Frequentation of PUGS in the year	0.92	4-point Likert scale	Survey
	Frequentation of PUGS in the week	0.90	5-point Likert scale	Survey
	Number of activities	0.90	Discrete, 16 categories	Survey
Intensity of use of PEGS	Frequentation of PEGS in the year	0.88	4-point Likert scale	Survey
	Frequentation of PEGS in the week	0.86	5-point Likert scale	Survey
	Number of activities	0.83	Discrete, 16 categories	Survey
Intensity and diversity of use of PRGS	Frequentation of PEGS in the year	0.90	4-point Likert scale	Survey
	Frequentation of PEGS in the week	0.88	5-point Likert scale	Survey
	Number of different private green spaces used	0.93	Discrete, 4 categories	Survey
	Number of activities	0.94	Discrete, 12 classes	Survey
	Number of different activities	0.95	Discrete, 4 classes	Survey
Diversity of use of public GS	Number of different activities	0.98	Discrete, 10 classes	Survey
	Number of different GS visited in the year	0.85	Discrete, 5 classes	Survey
	Level of landscape satisfaction from home	0.93	6-point Likert scale	Survey
Landscape satisfaction	Level of greenery visible from home	0.94	6-point Likert scale	Survey
	Proportion of trees visible from home	0.98	Continuous	PixScape
View of nature	Proportion of nature visible from home	0.98	Continuous	PixScape
	Average distance visible from home	0.63	Continuous	PixScape
Landscape openness	Maximum distance visible from home	0.99	Continuous	PixScape
	Dwelling floor area	1	Continuous	Survey
Noise exposure	Inverse of the average daily noise level at home	1	Continuous	MITHRA-SIG
PUGS accessibility	Gravity accessibility potential within a network distance of 500 m from home	0.98	Continuous	ModAccess
	Gravity accessibility potential within a network distance of 2000 m from home	0.99	Continuous	ModAccess
	Gravity accessibility potential within a network distance of 5000 m from home	0.99	Continuous	ModAccess
	Gravity accessibility potential within a network distance of 2000 m from home	0.99	Continuous	ModAccess
PEGS accessibility	Gravity accessibility potential within a network distance of 500 m from home	0.98	Continuous	ModAccess
	Gravity accessibility potential within a network distance of 2000 m from home	0.99	Continuous	ModAccess
	Gravity accessibility potential within a network distance of 5000 m from home	0.99	Continuous	ModAccess
PRGS area	Area of private GS at home	1	Continuous	GIS
Affinity with nature	Score for the importance of nature	1	5-point Likert scale	Survey
Contact with nature	Score for frequency and regularity of contact with nature	1	5-point Likert scale	Survey

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