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Looking beyond boundaries: Revisiting the rural-urban interface of Green Space Accessibility in Europe

Abstract

Improving Green Space Accessibility (GSA) in public spaces in cities and communities reduces disparities among people and fosters sustainable development. However, traditional mapping approaches in cities neglects green spaces in the hinterland and treats the geographical distance as a fixed quantity. This limits conclusions about spatial inequalities in Green Space Accessibility and influences the evaluation of current policies which seek to ensure a high local recreation quality for all residents irrespective of any administrative boundaries.

This paper aims to detect spatial inequalities in Green Space Accessibility for urban green (UG) and non-urban green (NUG) across Europe, and reveals the role of the rural-urban interface (RUI). The approach taken here calculates Green Space Accessibility across administrative boundaries, which enables distance to be treated as a flexible variable. The results highlight major inequalities between and within regions and countries. However, unequal Green Space Accessibility for urban green is compensated in most countries by more equal one for non-urban green, which is of particular relevance in the rural-urban interface.

The combined perspective on both relative and absolute Green Space Accessibility suggests a new perspective on the rural-urban interface that is critical for equitable green infrastructure planning. This paper concludes that, in order to bridge the urban-rural-divide, monitoring and planning tools that examine the arbitrary use of thresholds and existing administrative boundaries are needed.

Keywords: Green Space Accessibility, proximity, rural-urban interface, Europe, spatial planning

1. Introduction

By 2030, the UN aims to provide universal access to green and public spaces in cities and communities in order to reduce disparities amongst people (UN, 2015). Green Space Accessibility (GSA) is mostly conceptualised as physical distance and is thereby different from the pure availability of green spaces (Wüstemann et al., 2017; Biernacka and Kronenberg, 2019). GSA is defined as the relative opportunity for residents to reach any desired land-use activity from a given location (Handley et al., 2003; Ma and Haarhoff, 2015; Gregory, 1986). Due to ongoing urbanization and population pressure, GSA is usually mapped for cities as one element of recreational services. However, this rising demand in cities increases pressure on natural resources and ecosystem services outside of the administrative boundaries of cities (EP, 2016; EC, 2008).

These interactions between cities and their surrounding hinterland are conceptualised as the rural-urban interface (RUI), which is defined as a transition zone rather than a clear boundary (Simon, 2008; Rojas-Caldelas et al., 2008). The RUI is characterised by fragmented urban features within a landscape that still has rural elements (Ros-Tonen et al., 2015; Allen, 2003; Lerner and Eakin, 2011), leading to mixed land uses and functions with various demographic, economic and environmental flows (Simon, 2008; Rauws and de Roo, 2011). Recent processes of land take and ‘peri-urbanization’ put enormous pressure on the RUI and on its open (green) spaces as Nilsson et al. (2014) found for large parts of Europe. Environmental flows cover supporting, regulating, provisioning, and cultural ecosystem services but also environmental burdens like deforestation or pollution (Allen, 2003; MEA, 2005). In this paper, we do not consider all ecosystem services and flows but focus on the recreational function of green spaces as an important aspect of GSA.

A lack of urban green spaces and the overuse of urban parks leads to the increasing attractiveness of recreational possibilities outside of cities provided by peri-urban woody parks and forests (Soini et al., 2012; Seeland et al., 2002; Boll et al., 2014) while people in the city’s hinterland use green spaces of the corresponding city (Zasada et al. 2013). The resident’s demand for recreation and the emerging urban-rural and rural-urban flows are not dependent on administrative boundaries (Vries and Boer, 2008; Bell et al., 2007). However, prevailing approaches to GSA are limited in their analysis and consider only green spaces within the city’s administrative boundaries (Kabisch et al., 2016, Poleman, 2012; Pafi et al., 2016). As such, they produce uncertainties at the fringes due to the exclusion of green spaces outside of the defined boundaries.

Previous studies have not systematically differentiated between green space types such as parks or forest areas. Benefits and opportunities for recreation, however, differ between these two green space types (Rusche et al., 2019). In terms of analysing accessibility, forest areas play an important role in local and regional recreation and its associated social and health benefits (EEA, 2011; EC, 2012). In addition to urban parks, forest areas also provide ecosystem services that are beneficial to biodiversity and conservation. They also remove pollutants from the air, and provide habitats, carbon sequestration and carbon storage, as well as air temperature cooling and noise-reduction (Haase et al., 2016; Ma and Haarhoff 2015). In particular, forest areas at the fringe or in the hinterland of cities play an important role in the active and passive recreation of urban residents (Haase et al., 2014; Larondelle and Haase, 2017). Particularly, green spaces within short distances of residents' homes enable physical activities such as walking, running, mental contemplation or relaxation, a cool, noise-reduced and air-filtered environment, and promote social networking and inclusion (Kaplan and Kaplan, 2011; Wei, 2017).

For recreation, residents usually use green spaces close to their homes and the corresponding flows remain place-based (Zasada et al., 2013). The corresponding distance is not fixed but is sensitive to the spatial setting between users and green spaces. However, international recommendations as well as previous studies use fixed distances like 300, 500, 900 meters or 15 minutes walking distance (WHO, 2012) and assumed a strict dichotomy between residents supplied with green space and those who are deprived of it. But there is no consensus on how GSA should be measured (Wolch et al., 2014; Miyake et al., 2010; Mavoa et al., 2014). Undoubtedly, the distance relation between green spaces and residents' homes has to be represented by gradients that require the measure of distance. Due to city size, green space patterns and other terrain constraints, this distance measure, however, needs to be both systematic but flexible.

Addressing the mentioned drawbacks of previous studies would lead to a better understanding of the environmental flows between the demand and supply of green spaces and the ecosystem services that they provide (EP, 2016). Elaborating on our concept of GSA using a trans-boundary approach supports policies that seek to reduce spatial inequalities and to ensure the quality of life for residents in all parts of Europe – not just in cities (Rosa, 2014; Wei, 2017).

2. State of the art and objectives

Accessibility is a complex concept and there are many ways to define and measure it (Wang et al., 2013). Since the late 1950s, it developed from the potential for interaction into a multi-dimensional concept that addresses people's needs and the supply available. Its definition now includes evaluation of the extent to which planning was able to adequately respond to these needs (Hansen, 1959; Maruani and Amit-Cohen, 2007). In the 1970s, GSA was already understood as an expression of the quality of life of residents (Pred, 1977).

At the turn of the century, GSA was connected with the concept of environmental justice, which is based on the relationship between the unequal distribution of environmental stressors, the access to resources and social background (Sen, 2009; Szombathely, 2017). It is assumed that health benefits are increasing with better access to green spaces (Brulle and Pellow, 2006; Lee, 2002; Ma and Haarhoff, 2015). The corresponding benefits of GSA are the prevention of obesity, cancer, and osteoporosis, neurocognitive, cardiovascular, mental or immune improvements (Kuo, 2015; Lachowycz and Jones, 2014). While some authors have shown that the lowest socio-economic groups have higher GSA (Mitchell and Popham, 2008; Barbosa et al., 2007; Cutts et al., 2009), others have shown that the most-deprived neighborhoods have, on average, less available green space, and that which is available is of poor environmental quality in terms of air quality or heat stress (Grant et al., 2012; Comber et al., 2008). Crucially, equal access to a healthy environment and inequalities in GSA is strongly coupled to distance (Wolch, 2014; Dai, 2011; Jennings et al., 2012).

Distance as a physical GSA measurement can vary depending on the buffer, network, and floating Gaussian-based or Thiessen-polygon-based analysis (Dai, 2011; Comber et al., 2008; Ibes, 2015). For the operationalisation, Kimpton (2017) distinguished between provision, proximity,[1] and population pressure. Provision refers to the green space that is available within a distance from homes. It assumes that residents equally benefit from all surrounding green spaces, rather than their closest or most visited one (Astell-Burt et al., 2014; Mitchell & Popham, 2008). Proximity captures the travel distance from a residential home to a green space and assumes that residents only visit their nearest green space (Barbosa et al., 2007; Ham et al., 2012; Mavoa et al., 2014). Population pressure expresses the potential crowding of green areas (Dai, 2011; Ibes, 2015).

The improved availability of particularly spatial data and the advancement of methods have created more powerful approaches to detect GSA inequalities by enabling comparative analysis across Europe and complex approaches for case studies (Higgs et al., 2012, Neutens et al., 2010). Following a population pressure approach, Kabisch et al. (2016) used buffer analysis in 299 European cities in order to estimate the population count that can be supplied within a distance of 300m and 500m from urban green spaces and forest areas larger than two hectares. Poelman (2016) used network analysis and a 10-minute walking distance in order to calculate the proximity to urban green spaces and forest areas in almost 400 European cities. Similarly, Pafi et al. (2016) used network analysis and a 15-minute walking distance to estimate differences in GSA in selected European cities. Hence, although many studies have done an excellent job of reporting GSA, they used physical or travel-time distances as constants, thus producing static results (Wüstemann et al., 2017; Stanner and Bourdeau, 1995; Pauleit et al., 2003; Ma and Haarhoff, 2015; Handley et al., 2003).

However, distance varies with the mobility and preference of people approaching green spaces and the orientation of people is not related to administrative boundaries or fixed distance thresholds (Bell et al., 2007; Vries and Boer, 2008; Rosa, 2014). To our knowledge, so far no analysis has measured GSA (i) using distance as a flexible gradient; (ii) distinguished between green space types; and (iii) simultaneously analysed green spaces irrespective of administrative boundaries. Against this

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[1] Kimpton (2017) used the term "accessibility" which, however, overlaps with the conceptualization in this paper which uses proximity as one aspect of GSA defined as the distance to the nearest green space.

background, this paper aims at detecting spatial inequalities in European GSA by following three research questions:

1. How equal is GSA distributed across Europe?
2. What is the role of the rural-urban interface of GSA in Europe?
3. To what extend do urban residents benefit from green spaces beyond the administrative boundaries they live in?

3. Material and methods

In this study, we propose a raster-based approach for GSA assessment. This approach conceptualizes GSA as the population count within a given proximity to green spaces. Proximity is defined as the distance to the nearest patch of green space from any given residential location. Data processing was performed in Python and R with the pre-processing covering three steps (Figure 1).

Relevant land-uses were extracted from the CORINE Land Cover (CLC) 2012 dataset (Copernicus, 2018). This included the CLC classes *continuous and discontinuous urban fabric* for residential areas, and two complementary types of green: Urban green (UG), as defined by CLC class *green urban areas*; and non-urban green (NUG), corresponding to the CLC classes *broad-leaved, coniferous and mixed forest* (Figure 1A). Clearly, NUG may also be found in cities, e.g., in the form of riparian forests or woodland remnants. However, we refer to these classes as NUG due to their predominant association with the rural space.

Population was disaggregated to residential areas based on the GEOSTAT 1km² population grid with data available for 2011 (EUROSTAT, 2016). For this spatial disaggregation, a Simple Area Weighting approach was used (Li et al., 2007). I.e., the number of residential grid cells as given by CLC was determined within each 1 km² GEOSTAT grid cell, and the corresponding GEOSTAT population count uniformly distributed across them (Figure 1B). Hence, Simple Area Weighting assumes a homogeneous population density. The proximities p from each residential grid cell to the nearest patch of UG and NUG were subsequently computed (Figure 1C).

The findings presented in this paper were then calculated in five consecutive steps:

(i) First, GSA was calculated by aggregating population as a function of proximity to UG p_{UG} and to NUG p_{NUG} (Figure 1 D);

(ii) Second, the computed GSA was aggregated to countries and regions. This has been done by intersecting GSA with two additional layers—national borders and WUTS4 microregions (ESPON, 2014)—to derive proximity-population curves (Figure 1E). To reveal similarities in GSA at regional and national level, these proximity-population curves were then clustered. This has been done using a shape-based, average-linking hierarchical cluster algorithm (Euclidian distance, cf. Montero and Vilar, 2014), implemented in the dtwclust package for R (Sardá-Espinosa, 2018);

(iii) Third, for each grid cell, the relative GSA of a given type of green space was determined (Figure 1F). To do so, we propose two ratios, r_{UG} and r_{NUG}, based on the proximities p_{UG} and p_{NUG}, with $r_{UG} = p_{UG}/p_{NUG}$ and $r_{NUG} = p_{NUG}/p_{UG}$. If $r_{UG} = r_{NUG} = 1$, UG and NUG are equidistant from the current location. If, e.g., $r_{UG} = 0.5$, then the proximity to UG is half of that to NUG, and if $r_{UG} = 2$, the closest UG is twice as far away as the nearest NUG. Conversely, it can be assumed that the lower a ratio, the higher the relative GSA of the corresponding green type. From this, we postulate that a locally specific relative GSA r_{GSA} can be expressed as follows:

$$r_{GSA} = \begin{cases} r_{UG}, & if\ r_{UG} \leq r_{NUG}\ and\ r_{UG} \leq 0.6 \\ r_{NUG}, & if\ r_{UG} > r_{NUG}\ and\ r_{NUG} \leq 0.6 \\ \min(r_{UG}, r_{NUG}), & if\ r_{UG} \leq r_{NUG}\ and\ r_{UG} > 0.6 \\ & \quad or \\ & if\ r_{UG} > r_{NUG}\ and\ r_{NUG} > 0.6 \end{cases} \tag{1}$$

Following these assumptions and looking at Eq. (1), it follows that the case $r_{GSA} = r_{UG}$ characterizes areas that are predominantly supplied by UG. If $r_{GSA} = r_{NUG}$, areas are predominantly supplied by NUG. In both cases, the corresponding value for r_{GSA} will be comparatively low, with $r_{GSA} \leq 0.6$. The higher r_{GSA}, the higher the potential that a given location is supplied by UG *and* NUG simultaneously, as both types of green can be reached with about equal effort (Figure S3). We conceptualise such areas as the *rural-urban interface* (RUI). The RUI is described by the third case in Eq. (1), and is consequently defined as those areas where $r_{GSA} > 0.6$. This threshold value has been chosen as it is frequently used in statistics as a non-arbitrary cutting point that divides a sample into a smaller and larger sub-sample with contiguous intervals and in accordance to terciles (Ekstrom and Sorensen, 2014);

(iv) Fourth, the previously elicited relative GSA is further differentiated (Figure 1G). As the relative GSA r_{GSA} (cf. Eq. 1) neglects absolute proximity, we subsequently introduced a proximity threshold for p_{UG} and p_{NUG} of 1000m to further differentiate the *areas predominantly supplied by UG,* the *areas predominantly supplied by NUG,* and the *RUI* into (a) areas where both green types are nearby *(bi-supplied)*, with $p_{UG} \leq 1000m \wedge p_{NUG} \leq 1000m$; (b) areas near one of the green types *(mono-supplied)*, so that either $d_{UG} \leq 1000m \wedge d_{NUG} > 1000m$ or $d_{UG} > 1000m \wedge d_{NUG} \leq 1000\ m$; or (c) areas far away from both green types *(not-supplied)*, where $d_{UG} > 1000m \wedge d_{NUG} > 1000m$. This threshold value was chosen as a reasonable and widely used walking distance of 15 minutes (Pafi et al., 2016; WHO, 2012);

(v) Fifth, in order to compare the findings of this case study with already established studies, we calculated GSA for both green types simultaneously for 899 cities that were defined by Urban Audit delineations (EUROSTAT, 2018; cf. Figure 1H). We then assessed and compared the population count within a fixed distance of 1000m, first considering only green areas within administrative city boundaries similar to Kabisch et al. (2016); and secondly, according to the transboundary method proposed in this paper.

Figure 1: GIS-workflow with the five steps that led to the findings produced from the GSA approach.

4. Results

4.1 Inequalities of GSA in European countries 2012

Across Europe, the average proximity from residential areas to the nearest NUG is 1.79km (median 1.00km) with half of the European population living within approximately 1.48km of NUG. While regions such as Scandinavia, the Baltics, the Alps, the Pyrenees, the Dinaric Alps or the Iberian Peninsula show low proximities to NUG, islands such as Iceland, Crete or Sicilia, coastal areas around the North Sea, the western parts of the Adriatic Sea and the Aegean Sea, as well as continental areas such as Southern Spain or Dobruja (the Black Sea), are hotspots of high levels of proximity (Figure S1).

For UG, the average proximity is 20.62km (median 13.43km) with half of the European population living within 5.61km of UG. The proximities to UG are strongly related to the availability and distribution of UG in cities. Consequently, the proximity to UG in cities is comparatively low, but increases towards the rural space (Figure S1). Within 100km, the whole European population has access to UG while every European resident has access to NUG within 30km.

There are, however, considerable differences between the European regions. Figure 2A shows the cumulative share of the population with access to UG for countries grouped by regions. Clearly, with increasing proximity, the share of the population with access to UG increases accordingly. However, the steeper the curve, the lower the average proximity to UG, and the more equal GSA. An equal GSA can therefore be translated by a high population count in close proximity to the nearest UG. Looking at Figure 2A, access to UG is relatively equal in Northern Europe with 50% of its population located within 1.89km of UG (75% within 6.46km), followed by the west of Central Europe, with 50% of its population located within 4.89 km (75% within 15.29km). In Southern Europe, eastern Central Europe and in particular the Balkans, the avilability of UG in cities is lower and large parts of the population are located within higher proximities of UG, thus resulting in a more unequal GSA. In Southern Europe, 50% of the population lives within a proximity of 8.71km to UG, in eastern Central Europe 8.78km, and in the Balkans 20.91km (75% within 25.53km, 23.22km, and 41.66km, respectively).

Figure 2: Cumulative population share located within a given proximity to UG of up to 100km. (A) Country profiles are grouped by region; (B) Dendogram of the similarity of country profiles.

It also becomes clear that several European regions show comparatively high variations in GSA. While the majority of Northern European countries have a comparatively equal GSA, Western European countries have quite heterogeneous GSA, ranging between equal GSA in the Benelux countries and Germany, and rather unequal access to UG in the Alpine countries and France. Southern European countries show a relatively homogeneous GSA, while eastern Central Europe and the Balkans are again quite heterogeneous with equal GSA in the Baltic, Serbia and Bulgaria. Slovakia, Slovenia, Poland, Bosnia, Kosovo or Macedonia tend to have more unequal GSA.

Consequently, a country's GSA can be more similar to countries outside of the corresponding region than to other regional candidates. The cluster analysis of the country profiles in Figure 2A provides a more integrative, cross-regional perspective of GSA. The results in Figure 2B show that Spain performs more like France or Poland compared to countries of the same southern region such as Italy or Greece, which, in turn, are more similar to the Balkan countries. However, Serbia and Bulgaria perform similarly to Austria or Portugal, and are thereby significantly different to other regional candidates such as Albania or Romania. The Baltic countries perform more similarly to Northern Europe, e.g. Sweden performs similarly to Latvia, the UK compares closely with Lithuania, and Ireland is similar to Estonia.

4.2 Revisiting the rural-urban interface for GSA in Europe

An unequal GSA for UG can be potentially compensated for by access to NUG, which is generally more equal than for UG. For instance, eastern Central Europe is characterised by an equal access to NUG when compared to Northern Europe (Figure S2). Additionally, we identify residential areas that are likely to be served by both types of green: the rural-urban interface (RUI).

As Figure 3 shows, 62% of the population across Europe is located in areas predominantly supplied by NUG, 25% in areas predominantly supplied by UG, and 13% within the RUI. In almost all countries except Iceland, Malta and the UK, the share of the population in areas predominantly supplied by NUG exceeds the population share within areas predominantly supplied by UG. In particular, in Finland, Italy, Portugal, Switzerland, Belgium, Luxemburg, as well as large parts of Eastern Europe and the Balkans, half of the population is predominantly supplied by NUG. Malta, Iceland, Ireland, the Baltic countries, Denmark, Sweden, the Netherlands, Bulgaria, Montenegro, and Spain are all countries in which more than 30% of the population is predominantly supplied by UG.

The larger the population that is supplied by the RUI is, the higher is the share of the population that is predominantly supplied by UG. Although the RUI is small regarding its overall spatial extent (cf. Figure 4), it plays an important role in agglomerations of Spain, Germany or France with a population share of

12–14% located within the RUI. With more than 15% of the nation's population covered, the RUI is of particular significance in the Netherlands, the Baltic countries, the UK, Malta, Ireland, and Serbia.

Figure 3: Share of the population residing within each of the three derived classes of green supply.

4.3 Proposing a typology of absolute and relative GSA

The aforementioned classes of green supply constitute a relative dimension of GSA. Hence, to relate these findings to previous studies, the absolute dimension of GSA needs to be integrated by considering the proximity to UG and NUG. By doing so for each of the three classes, a total of nine categories can be derived: areas within 1000m of UG *and* NUG (bi-supplied); areas within 1000m of UG *or* NUG (mono-supplied); and areas further away (not-supplied). The resulting continuous GSA for Europe is mapped in Figure 4 whereas the population share within each of these categories is shown in Figure 5.

Figure 4: Classes of green supply considering the absolute dimension of GSA for 2012, based on the relative potential and the absolute proximity to UG and NUG.

In areas *predominantly supplied by NUG*, 53% of the population has access to either one of the green space types within 1000m (mono-supplied), whilst for 46%, UG and NUG is further than 1000m (not-supplied). Thirty-five percent of the European population living in areas *predominantly supplied by UG* does not have access to either one of the green space types within 1000m and 60% is mono-supplied by UG. Highly urbanised countries generally have a high share of the population located in mono-supplied areas and to both green space types (bi-supplied) in areas with low proximities. These are countries with primate cities such as Luxembourg, or with a relatively balanced settlement structures, e.g., Sweden, Norway, Finland, or the Czech Republic (Figure 5). Examples of insufficient access to UG, and therefore a lack of compensating NUG within walking distance, include cities in the Po Valley (Italy), Greece, or agglomerations such as Tirana, Zagreb, Valetta, Madrid, and Paris.

Within the RUI, 77% of the population lives in not-supplied areas. However, 14% of its population has short proximities to both green types (bi-supplied). This share is substantially higher than for the other two classes (predominantly supplied by UG 5%; and 2% for those predominantly supplied by NUG). This underlines the importance of the RUI for GSA assessment. For example, 34% of the Dutch population is predominately supplied by UG, and 45% by NUG, respectively. Thereof, in the former case, about 60% of the population benefits from low proximities to both or either green type (bi- or mono-supplied), while this value is 42.3% of the population in the latter case. Due to the polycentric structure of the Randstad, the RUI plays an important role both spatial terms as well as in the covered total population that amounts to 21% (Figures 4A). However, large forest areas such as the Veluwe (Netherlands) are rather compact and distant to agglomerations. Hence, urban residents only experience limited benefits from these areas, as 85% of the population within the RUI is located in not-supplied areas, and only a small percentage of people (7%) benefit from close proximity to both UG and NUG.

Similar examples of a comparatively large RUI, with green spaces more than 1000m away from more than 80% of the RUI population, are Malta, Greece, the UK, and Serbia. The majority of the Serbian population (65%) is predominantly supplied by NUG, although 61% of these inhabitants are located in not-supplied areas. In the Vojvodina region (northern Serbia, Figure 3B), the low degree of urbanisation and the lack of NUG result in the large spatial extent of the RUI. About 15% of the Serbian population lives within the RUI, and green spaces are more than 1000m away for about 87% of these inhabitants. Similar patterns with high shares of the population in not-supplied areas within predominantly NUG-supplied areas and within the RUI can be found, e.g., in the southern Balkan region (Kosovo, Macedonia, Albania, Greece), Malta, Ireland, and Italy (Figure 3).

Polycentric areas such as the agglomerations of the Ruhr and Bergisches Land (western Germany) further highlight the role that NUG can play in meeting citizen demand. In the Ruhr region, scattered UG and NUG, in close proximity however, form green space corridors that allow residents to split or distribute their recreational needs between different types of green (Figure 3C). Consequently, the simultaneous and complementary existence of UG and NUG within walking distances results in comparatively large bi-supplied areas, where both green space types are easily accessible and, as seen from the RUI, are also roughly within equal proximity. In the Bergisches Land, it can be seen that NUG is closely located to residential areas, supports UG corridors and relieves pressures on UG, by providing additional recreation alternatives at the urban fringe (Figure 3D). Other examples where the RUI bi-supplied area covers high population shares, include the Scandinavian countries, Iceland, the Baltic countries, Slovenia, the Czech Republic, Luxemburg, and Germany.

Figure 5: Share of the population (2012) within classes of supply. (A) areas predominantly supplied by UG. (B) RUI. (C) areas predominantly supplied by NUG.

5. Discussion

Our proposed approach has identified geographic variations in terms of the proximity to green spaces (i) independent of arbitrary thresholds, and (ii) irrespective of any administrative boundaries, which can (iii) be used for an alternative planning perspectives on the RUI. This will be discussed in the following section in relation to our research questions.

5.1 Pan-European inequalities in GSA

Patterns of GSA across Europe are the complex result of demographic and physical settings (Linard et al., 2012). First, and in line with previous studies, the results underline the importance of other green spaces apart from UG for the green supply of Europe's residents (Rusche et al., 2019; Wolff and Haase, 2019). It has been shown that the median proximity to UG is about 13 times larger than to NUG. In most countries, and as exemplified by the Scandinavian countries, NUG is located more closely to residents than UG (Hauru et al., 2015). However, in Belgium and Italy a substantial share of the population suffers from being very distant from NUG. In sparsely populated areas, residents are not proximate to NUG due to altitude (Norway), climate (the East-West discrepancy in Greece), soil-water conditions (Serbia, Iceland), or large-scale deforestation (Spain, Grove and Rackham, 2003).

Second, inequalities of GSA differ between and within the European countries. Highly urbanised and densely populated countries with a balanced distribution of cities across the entire country such as Germany, the Benelux countries, or the UK, as well as countries where the majority of the nation's population is concentrated in cities, such as in Sweden or the Baltic countries, show low inequalities in the supply of population located near UG. In contrast, Italy, Austria, France, Greece or Bosnia are characterised by high inequalities in terms of GSA to UG. It must therefore be noted that there are no clear regional dependencies, however, similarities in GSA can be detected between countries of different regions.

Third, people have different access to benefits of ecosystem services (ES) as the proximity between residential areas and green spaces – between ES benefiting and providing areas (Fischer et al., 2009) – varies tremendously.

While every European resident has access to NUG within 30 km, access to UG is more restricted such that stronger inequalities for UG are generally detectable in limiting quality of life (Martinico et al. 2014). Residents with comparably high proximities to green spaces see no significant benefit from ecosystem services ES (Gómez-Baggethun and Barton, 2013). These ES-deficit areas are measured by the relation between grey and green infrastructure in spatially explicit assessments (Spyra et al., 2019). Our approach adds a GSA perspective that defines ES deficit areas as residential areas that are located beyond a certain proximity to either UG or NUG. These areas are designated as not-supplied in the proposed approach and cover high population shares in Greece, the Netherlands or the United Kingdom that require particular attention from urban and regional planning (Heckert and Rosan, 2016).

However, an unequal GSA for UG is compensated for in most countries by a more equal GSA for NUG – especially in eastern Central Europe. These ecological compensation effects rarely match administrative boundaries and are particularly obvious in the RUI in which 13% of Europe's population resides. Within the RUI, residential areas are equally distant from UG and NUG, which induces bidirectional flows for recreation (urban–rural, rural–urban). Similar approaches have used indicators for performing a spatially explicit quantification of the degree of urbanisation and the potential provision of ES (Wandl et al., 2014; Inostroza et al., 2019; Spyra et al., 2019). The pattern that is emerging from these studies better mirrors the spatial complexity of recreational green spaces. Our paper adds one aspect of ecological connectivity of fringe areas.

Within the RUI, a substantially higher share of population has a high relative and absolute GSA – for example, in Sweden, Latvia or the Czech Republic when compared to areas that are predominantly supplied by UG or NUG. As for these bi-supplied areas, both green space types are equally distant and within walking distance and represent the optimal spatial green infrastructure in which residents can equally benefit from the different ecosystem services these green space types provide (EEA, 2011). The Rhine-Ruhr Area is a good example of compensation effects as various green space types serve the recreational demands of residents. Due to these recreational alternatives, pressures on green areas due to overuse might decrease – bi-supplied areas thus play a major role for the GSA of the wider metropolitan system (Ros-Tonen et al., 2015). These effects are particularly promising for polycentric agglomerations in which development corridors for energy, housing or infrastructure compete with recreational areas (Inostroza, 2017; Taubenböck et al., 2014) but are challenging for both spatial monitoring and planning.

5.2 Benefits and uncertainties of the approach

Previous studies are limited by pre-defined administrative boundaries, thus underestimating GSA at the fringe of cities. An analysis of 899 European cities using a 1000 m proximity revealed differences between the presented methodology and traditional approaches (Kabisch et al., 2016). This difference was measured as a share of the observed difference in a well-supplied population to the corresponding population count that was identified by the traditional method – ranging from 0.001% to 3012.19% (mean 9.78%). Across all cities, 876,771 people were additionally identified as being well-supplied by green areas outside of the cities' boundaries, a population count that is almost identical to the population of Stockholm (2012). For 54.1% of all cities (486 cities) differences can be detected. On average, 1.20% of the total city population in 2012 (median 0.33% or 568.44 inhabitants) are being additionally identified as well-supplied by the proposed methodology – particularly in England, the Benelux, East Central Europe and the Balkan (Figure 6). As this provides a different spatial picture than previous studies (e.g. Poleman, 2012), we consequently agree with previous studies (Ham et al., 2012; Mavoa et al., 2014) that results are sensitive to the chosen threshold, but add that the chosen boundaries have at least the same impact on the results.

Figure 6: Absolute and relative difference between the proposed methodology and established approaches (see Kabisch et al., 2016).

There are, however, three limitations to the presented approach. First, due to CLC's low resolution (its 25-ha minimum mapping size) land-use classes such as urban green may be underrepresented in urban areas while residential areas could be underrepresented, particularly in rural areas (Meinel et al., 2007). Shrubs or grasslands are important in some Mediterranean or northern European countries, but haven't been considered as the approach focuses on green space types that are commonly used in European studies as areas of recreation (Poelman, 2016; Kabisch et al., 2016; Pafi et al., 2016). The assumption of homogeneous population density may lead to inaccuracies in the spatial disaggregation of the population. Second, the use of physical (i.e. Euclidian distances) to calculate proximities neglects potential physical barriers, and may estimate walking distances inaccurately compared to network-based approaches (Poelman, 2016; Pafi et al., 2016). Third, the proposed approach defines GSA by proximity, assuming that all green spaces are potentially accessible without restrictions due to ownership, quality or other barriers that are not represented in the underlying dataset (Wüstemann et al., 2017; Handley et al., 2003).

This paper conceptualises GSA by combining a provision and proximity analysis (Kimpton, 2017). In so doing, it produces an individual proximity to any given green space, independent of administrative boundaries and fixed supply-thresholds. CLC is used as it is currently the most suitable, robust and consistent land-use dataset and allows a pan-European analysis of different green space types as well as subsequent change detection (EEA, 2011). Urban Atlas represents a good alternative but covers larger cities and, most crucially, provides data within Functional Urban Areas (Copernicus, 2019) that would have disregarded our arguments concerning the independence of pre-given boundaries. Still, Urban Atlas is of advantage for detecting inner-city green space elements (for a comparison between different data see BBSR, 2013; Feltynowski et al, 2018). Using network analysis that considers streets and barriers is a suitable alternative (Wandl et al., 2014) but would have required detailed and costly data and substantially higher computational power. However, network analysis may underestimate informal routes (Cutts et al., 2009) and it has been shown that the differences to buffer-based GSA approaches are too small to moderate and decrease with distance (Richter et al., 2016).

For future research, in order to add to the complexity of GSA, it is recommended that further studies focus on the different characteristics of users and the role of perception, attractiveness or avoidance of green spaces and the corresponding physical, institutional, or mental barriers (Park, 2017; Wang, 2013; Biernacka and Kronenberg, 2018).

5.3 A new planning perspective on the rural-urban interface

The approach taken here has suggested a new perspective on RUI which is defined as a zone in which UG and NUG can be reached within a similar proximity. The role of the RUI for recreational purpose will increase due to rising densities in congested agglomerations with few green spaces (Vries and Boer, 2008). This is even more challenging as planning focusing on the built-environment and planning focusing on the natural environment are two “competing lenses within which to view, manage and improve policy decisions” (Scott et al., 2013:3). Giving this, governance processes are needed that produce synergies between resource sustainability and human wellbeing (Seitzinger et al. 2012; Rojas-Caldelas et al., 2008). In addition, we state that the RUI is most critical for equitable green infrastructure planning. However, it is also most promising for sustainable planning and seeks to optimise the distribution of human activities and land use as well as bridge the urban-rural divide in spatial planning (EP, 2016).

First, appropriate tools are needed for planning both green and grey infrastructures. Thereby, equal GSA in terms of acceptable proximities for residents as well as accessibility to multiple types of green have to be ensured. Planning strategies should focus on the protection of existing green rings or corridors at the fringe, the implementation of regulations for land use and the prevention of habitat loss, which cannot always be enforced under existing legislation (EEA, 2011). This needs to be combined with the concentration of densification within low-density built-up areas and along public transportation nodes within the periurban areas (Westerink et al., 2013). Thereby, the presented approach can serve as a tool that allows the aggregation of population within any proximity threshold to different green spaces and thus, in the best case, counteracting the periurban sprawling which would, in the worst case, diminish or eliminate identified rural GSA in bordering districts—RUI—of cities.

Second, goal conflicts need to be mitigated both between different and among the same land uses independent of administrative boundaries (Geneletti et al., 2017; Spyra et al., 2019:44). Solutions are needed to mitigate competing demands for recreation and housing through resource-efficient infrastructures and built-up structures (UN, 2015). Moreover, conflicts between green goals need to be mitigated, e.g. between food production and recreational purposes on open and green spaces (Ros-Tonen et al., 2015). This could be framed by fostering multifunctional landscapes with accessible social, economic and environmental potential (Rauws and de Roo 2011).

Third, as neither exclusively urban nor exclusively rural policies are suitable for improving the GSA in the RUI (Rauws and de Roo, 2011), nested coalitions of decision makers are needed. As the RUI is not attached to a city’s boundary, collaborative planning should engage with nearby local stakeholders, regional and national actors, as well as the inhabitants that they affect (Seitzinger et al., 2012; Soini et al., 2012; Hansen et al, 2016). A nested configuration such as this is needed as various policy fields, including transportation and environment, are concerned with different land use objectives, trade-offs and institutional characteristics (Sayer et al., 2013). The proposed RUI as a measure of the relative dimension of GSA provides an evidence-based spatial assessment, which could foster communication and adaptive learning within multi-stakeholder processes (Ros-Tonen et al., 2015).

6. Conclusions

A transboundary proximity approach for different green space types has been used here for accessing GSA. Thereby, this paper revealed GSA inequalities and analytically interrogates the arbitrary use of thresholds in European countries, thus adding an aspect of environmental justice to previous green space mapping studies. From a governance perspective, this would facilitate equal access by redefining resource-allocation questions in order to improve human well-being. The study underlines the sensitivity of monitoring results to the setting of administrative boundaries, which is particularly challenging when spatial planning is still oriented on the urban-rural dichotomy. The different perspective of the RUI suggested in this paper allows the acknowledgement of the various social and environmental interactions within these areas. The results provide a platform for a collaborative dialog and seek to mitigate the contrasting relation between built-up and natural elements in strategic planning processes at the urban fringe and beyond. With the conceptualization and the quantitative spatial assessment suggested in this paper, planners and scholars are provided with a tool that delivers precise and usable results on the spatial heterogeneity of GSA in order to deduce space-sensitive strategies for equal spatial development.

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References

Allen, A. 2003. Environmental planning and management of the peri-urbaninterface: Perspectives on an emerging field. Environment and Urbanization 15(1): 135–148, http://dx.doi.org/10.1177/09562478030150010

Astell-Burt, T., Feng, X., Mavoa, S. et al. 2014. Do low income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. BMC Public Health 14(1): 1-11

Barbosa, O., Tratalos, JA., Armsworth, PR. et al. 2007. Who benefits from access to green space? A case study from Sheffield, UK. Landscape and Urban Planning 83 :187–195

BBSR (Federal Institute for Research on Building, Urban Affairs and Spatial Development) 2013. Neuere Flächennutzungsdaten. BBSR-Analysen KOMPAKT 02/2013, Bonn.

Bell, S., Tyrväinen, L., Sievänen, T., Pröbstl, U., Simpson M. 2007. Outdoor recreation and nature tourism: A European perspective. Living Reviews in Landscape Research 1(2): 1–46

Biernacka, M., Kronenberg, J. 2018. Classification of institutional barriers affecting the availability, accessibility and attractiveness of urban green spaces. Urban Forestry & Urban Greening 36: 22-33

Boll, T., von Haaren, C., von Ruschkowski, E. 2014. The Preference and Actual Use of Different Types of Rural Recreation Areas by Urban Dwellers - The Hamburg Case Study. PLoS ONE 9(10): e108638. doi:10.1371/journal.pone.0108638

Brulle, RJ., Pellow, DN. 2006. Environmental justice: Human health and environmental inequalities. Annual Review of Public Health 27: 103–124

Comber, A., Brundson, C., Green, E. 2008. Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. Landscape and Urban Planning 86:103–114

Copernicus 2018. Corine Land Cover 2012. Available from: https://land.copernicus.eu/pan-european/corine-land-cover [Accessed: 15th May 2018]

Copernicus 2019. Urban Atlas 2012. Available from: https://land.copernicus.eu/local/urban-atlas [Accessed: 8th April 2019]

Cutts, BB., Darby, KJ., Boone, CG. et al. 2009. City structure, obesity, and environmental justice: An integrated analysis of physical and social barriers to walkable streets and park access. Social Science & Medicine 69(9): 1314-1322

Dai, D. 2011. Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? Landscape and Urban Planning 102(4): 234-244

ESPON European Observation Network for Territorial Development and Cohesion. 2014. ESPON 2013 Database Dictionary of Spatial Units. Nomenclature of WUTS World Unified Territorial System

EC European Commission 2008. Green Paper on Territorial Cohesion. CSM1 4/161 B-1049. Brussels.

EC European Commission 2012. The Multifunctionality of Green Infrastructure, Science for Environment Policy, Indepth Reports, March 2012, DG Environment

EEA European Environment Agency 2011. Green infrastructure and territorial cohesion. The concept of green infrastructure and its integration into policies using monitoring systems. EEA Technical report No 18/2011

Ekstrom, CT., Sørensen, H. 2014. Introduction to Statistical Data Analysis for the Life Sciences. 2nd Edition, Chapman and Hall/CRC, New York

EP European Parliamentary 2016. Bridging the rural-urban divide Rural-urban partnerships in the EU. Research Service, Briefing. European Union

EUROSTAT 2016. GEOSTAT 2012 grid dataset [Accessed: 15th May 2018]

EUROSTAT 2018. Urban Audit Database – © EuroGeographics for the administrative boundaries. Available from: https://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units/urban-audit#ua11-14 [Accessed: 7th November 2017].

Feltynowski, M., Kronenberg, J., Bergier, T., Kabisch, N., Łaszkiewicz, E., Strohbach, M. 2018. Challenges of urban green space management in the face of using inadequate data. Urban Forestry and Urban 31: 56-66.

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecol. Econ. 68(3), 643–653

Geneletti, D., Rosa, D., Spyra, M., Cortinovis, C. 2017. A review of approaches and challenges for sustainable planning in urban peripheries. Landscape and Urban Planing 165: 1–13, https://doi.org/10.1016/j.landurbplan.2017.01.013

Gómez-Baggethun, E., Barton, DN. 2013. Classifying and valuing ecosystem services for urban planning. Ecological Economics 86, 235–245, http://dx.doi.org/10.1016/j.ecolecon.2012.08.019

Grant, M., Bird, C., Marno, P. 2012. Health inequalities and determinants in the physical urban environment: Evidence briefing. Bristol. WHO Collaborating Centre for Healthy Urban Environments, University of the West of England

Gregory, D. 1986. Accessibility. In: Johnston RJ, Gregory D and Stoddart DR eds.. Dictionary of Human Geography. Oxford, England: Blackwell, 2nd ed. p. 2.

Grove, AT., Rackham, O. 2003. The Nature of Mediterranean Europe: An Ecological History. Yale University Press, Yale

Haase, D., Kabisch, N., Pintar, M. et al. 2016. Classification of UGI based on their functionality, services, synergies, trade-offs and spatial conflicts. GREEN SURGE deliverable 3.3, University of Copenhagen

Haase, D., Larondelle, N., Andersson, E. et al. 2014. A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. Ambio 43:413–433

Ham, C., Champ, PA., Loomis, JB. et al. 2012. Accounting for heterogeneity of public lands in hedonic property models. Land Economics 88(3): 444-456

Handley, J., Slinn, P., Barber, A. et al. 2003. Accessible natural green space standards in towns and cities: A review and toolkit for their implementation. Peterborough, English Nature

Hansen, WG. 1959. How accessibility shapes land use. Journal of the American Institute of Planners 25(2): 73-76

Hansen, R., Rolf, W., Santos, A. et al. 2016. Advanced Urban Green Infrastructure Planning and Implementation - Innovative Approaches and Strategies from European Cities. Deliverable5.2. GREEN SURGE.

Hauru, K., Eskelinen, H., Yli-Pelkonen, V. et al. 2015. Resident's perceived benefits and the use of urban nearby forests. Int. J. Appl. For. 1–23

Heckert, M., Rosan, CD. 2016. Developing a green infrastructure equity index to promote equity planning, Urban Forestry & Urban Greening 19: 263-270

Higgs, G., Fry, R., Langford, M. 2012. Investigating the implications of using alternative GIS-based techniques to measure accessibility to green space. Environment and Planning-Part B 39: 326

Ibes, DC. 2015. A multi-dimensional classification and equity analysis of an urban park system: A novel methodology and case study application. Landscape and Urban Planning, 137, 122e137. http://dx.doi.org/10.1016/j.landurbplan.2014.12.014

Inostroza, L., Hamstead, Z., Spyra, M., Qureshi, S. 2019. Beyond urban–rural dichotomies: Measuring urbanisation degrees in central European landscapes using the technomass as an explicit indicator. Ecological Indicators 96(1): 466-476, ttps://doi.org/10.1016/j.ecolind.2018.09.028

Jennings, V., Johnson-Gaither, C., Gragg, RS. 2012. Promoting environmental justice through urban green space access: A synopsis. Environmental Justice 5(1): 1–7

Kabisch, N., Strohbach, M., Haase, D. et al. 2016. Urban green space availability in European cities, Ecological Indicators 70: 586-596

Kaplan, R., Kaplan, S. 2011. Well-being, Reasonableness, and the Natural Environment. Applied Psychology: Health and Well-Being 3: 304-321

Kimpton, A. 2017. A spatial analytic approach for classifying greenspace and comparing greenspace social equity, Applied Geography 82: 129-142

Kuo, M. 2015. How might contact with nature promote human health? Promising mechanisms and a possible central pathway. Frontiers of Psychology 25: 1093

Lachowycz, K., Jones, AP. 2014. Does walking explain associations between access to greenspace and lower mortality? Social Science & Medicine 107: 9-17

Larondelle, N., Haase, D. 2017. Back to nature! Or not? Urban dwellers and their forest in Berlin. Urban Ecosystems 20(5): 1069–1079 https://doi.org/10.1007/s11252-017-0660-7

Lee, C. 2002. Environmental justice: Building a unified vision of health and the environment. Environ. Health Perspect. 2: 141–144

Lerner AM., Eakin H. 2011. An obsolete dichotomy? Rethinking the rural–urban interface in terms of food security and production in the global south. Geographical Journal 177(4): 311–320

Li, T., Pullar, D., Corcoran, J. et al. 2007. A comparison of spatial disaggregation techniques as applied to population estimation for South East Queensland SEQ), Australia. Applied GIS 3(9): 1-16

Linard, C., Gilbert, M., Snow, R.W., Noor, A.M., Tatem, A.J., 2012. Population distribution, settlement patterns and accessibility across Africa in 2010. PLoS One 7. https://doi.org/10.1371/journal.pone.0031743

Ma, J., Haarhoff, E. 2015. The GIS-based Research of Measurement on Accessibility of Green Infrastructure–A Case Study in Auckland. In: MIT's 14th International Conference on Computers in Urban Planning. Boston, United States

Martinico, F., La Rosa, D., Privitera, R. 2014. Green oriented urban development for urban ecosystem services provision in a medium sized city in southern Italy. IForest 7(6): 385–395

Maruani, T., Amit-Cohen, I. 2007. Open space planning models: A review of approaches and methods. Landscape and Urban Planning 81: 1-13

Mavoa, S., Koohsari, MJ., Badland, HM. et al. 2014. Area-level disparities of public open space: A geographic information systems analysis in metropolitan Melbourne. Urban Policy and Research 1-18

MEA 2005. Ecosystems and human well-being: synthesis. Island Press, Washington DC

Meinel, G., Schubert, I., Siedentop, S. et al. 2007. Europäische Siedlungsstrukturvergleiche auf Basis von CORINE Land Cover – Möglichkeiten und Grenzen. In: Schrenk M, Popovich V, Benedikt J: REAL CORP Proceedings 2007, Wien, Austria, May 20-23, pp. 645-656

Mitchell, R., Popham, F. 2008. Effect of exposure to natural environment on health inequalities: An observational population study. The Lancet 372(9650): 1655-1660

Miyake, KK., Maroko, AR., Grady, KL. et al. 2010. Not just a walk in the park: methodological improvements for determining environmental justice implications of park access in New York City for the promotion of physical activity. Cities and the Environment 3(1): 1–17

Montero, P., Vilar, JA. 2014. TSclust: An R Package for Time Series Clustering. Journal of Statistical Software 62(1): 1-43

Neutens, T., Schwanen, T., Witlox, F. et al. 2010. Equity of urban service delivery: a comparison of different accessibility measures. Environment and Planning A 42: 1613-1635

Nilsson K., Nielsen TS., Aalbers C., Bell S., Boitier B., Chery JP., Fertner C., Groschowski M., Haase D., Loibl W., Pauleit S., Pintar M., Piorr A., Ravetz J., Ristimäki M., Rounsevell M., Tosics I., Westerink J., Zasada I. 2014. Strategies for Sustainable Urban Development and Urban-Rural Linkages. Research brief, March 2014, European Journal of Spatial Development.

Pafi, M., Siragusa, A., Ferri, S. et al. 2016. Measuring the Accessibility of Urban Green Areas. A comparison of the Green ESM with other datasets in four European cities. JRC technical report EUR 28068 EN. Luxembourg

Park, K. 2017. Psychological park accessibility: a systematic literature review of perceptual components affecting park use. Landsc. Res. 42: 508–520

Pauleit, S., Slinn, P., Handley, J. et al. 2003. Promoting the Natural Greenstructure of Towns and Cities: English Nature's "Accessible Natural Greenspace Standards" Model. Built Environment 1978: 157-170

Poelman, H. 2016. A walk to the park? - assessing access to green urban areas in Europe's cities. European Commission, Brussels

Pred, AR. 1977. City-systems in Advanced Economies: Past Growth, Present Processes and Future Development Options. London: Hutchinson

Rauws, WS., de Roo, G. 2011. Exploring transitions in the peri-urban area. Planning Theory & Practice 12(2): 269–284

Richter, B., Grunewald, K., Meinel, G. 2016. Analyse von Wegedistanzen in Städten zur Verifizierung des Ökosystemleistungsindikators „Erreichbarkeit städtischer Grünflächen“, AGIT - Journal für Angewandte Geoinformatik 2: 472-781, http://dx.doi.org/10.14627/537622063

Rojas-Caldelas, R., Ranfla-González, A., Pena-Salmon, C., VenegasCardoso, R., Ley-Garcia, J., Villegas-Olivar, O. and Leyva-Camacho, O. 2008. Planning the rural-urban interface under sustainable principles: A methodological proposal. The Sustainable City V: 641 – 649.

Rosa, DL. 2014. Accessibility to greenspaces: GIS based indicators for sustainable planning in a dense urban context. Ecological Indicators 42: 122–134

Ros-Tonen, M., Pouw, N., Bavinck, M. 2015. Governing Beyond Cities: The Urban-Rural Interface. In: Gupta J., Pfeffer K., Verrest H., Ros-Tonen M. eds. Geographies of Urban Governance. Springer, Cham.

Rusche, K., Reimer, M., Stichmannosa, R. 2019. Mapping and Assessing Green Infrastructure Connectivity in European City Regions. Sustainability 11 1819. doi:10.3390/su11061819

Sardá-Espinosa, A. 2018. Comparing Time-Series Clustering Algorithms in R Using the dtwclust Package. Available online: https://cran.r-project.org/web/packages/dtwclust/vignettes/dtwclust.pdf [08.01.2019]

Sayer, J., Sunderland, T., Ghazoul, J., Pfund, JL., Sheil, D., Meijaard, E., Venter, M. et al. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc Natl Acad Sci U S A 21:8349–8356

Scott, AJ., Carter, C., Reed, MR., Larkham, P., Adams, D., Morton, N., Coles, R. 2013. Disintegrated development at the rural–urban fringe: Re-connecting spatial planning theory and practice. Progress in Planning 83:1–52, http://dx.doi.org/10.1016/j.progress.2012.09.001

Seeland, KT., Moser, K., Scheuthle, H., Kaiser, FG. 2002. Public acceptance of restrictions imposed on recreational activities in the peri-urban Nature Reserve Sihlwald, Switzerland. Urban Forestry & Urban Greening 1: 49-57

Seitzinger, SP., Svedin, U., Crumley, CL., Steffen, W., Abdullah, SA., Alfsen, C., Broadgate, WJ. et al. 2012. Planetary stewardship in an urbanizing world: beyond city limits. Ambio 8: 787–794

Sen, A. 2009. The Idea of Justice. Cambridge, MA, USA: Belknap Press of Harvard University Press

Simon, D. 2008. Urban environments: issues on the peri-urban fringe. Annual Reviews of Environment and Resources 33: 167–185, https://doi.org/10.1146/annurev.environ.33.021407.093240

Soini, K., Vaarala, H., Pouta, E. 2012. Residents’ sense of place and landscape perceptions at the rural–urban interface. Landscape and Urban Planning 104(1): 124–134

Spyra, M., Inostroza, L., Hamerla, A. et al. 2019. Ecosystem services deficits in cross-boundary landscapes: spatial mismatches between green and grey systems. Urban Ecosyst 22: 37-47 https://doi.org/10.1007/s11252-018-0740-3

Stanners, D., Bourdeau, P. 1995. Europe's Environment: The Dobris Assessment. European Environment Agency, Copenhagen

Szombathely, M., von Albrecht, M., Antanaskovic, D. et al 2017. A Conceptual Modeling Approach to Health-Related Urban Well-Being. Urban Sci. 2017(1): 17

Taubenböck, H., Wiesner, M., Felbier, A., Marconcini, M., Esch, T., Dech, S. 2014. New dimensions of urban landscapes: The spatio-temporal evolution from a polynuclei area to a mega-region based on remote sensing data. Applied Geography 47: 137-153, https://doi.org/10.1016/j.apgeog.2013.12.002.

UN United Nations 2015. Transforming our world: the 2030 Agenda for Sustainable Development. Resolution A/RES/70/1. In: Seventieth session United Nations General Assembly, Agenda items 15 and 116

Vries, S., Boer, TA. 2008. Recreational accessibility of rural areas: its assessment and impact on visitation and attachment. Forest Recreation & Tourism Serving Urbanised Societies. Finnish Forest Research Institute

Wandl, A., Nadin, V., Zonneveld, W., Rooij, R. 2014. Beyond urban–rural classifications: Characterising and mapping territories-in-between across Europe. Landscape and Urban Planning 130, 50-63, https://doi.org/10.1016/j.landurbplan.2014.06.010

Wang, D., Iderlina, MB., Gregory, B. 2013. Rethinking Accessibility in Planning of Urban Open Space Using an Integrative Theoretical Framework. Final Paper Submitted to State of Australian Cities Conference 2013

Wei, F. 2017. Greener urbanization? Changing accessibility to parks in China. Landscape and Urban Planning 157: 542-552

Westerink, J., Haase, D., Bauer, A., Ravetz, J., Jarrige, F., Aalbers C.B.E. M. 2013. Dealing with Sustainability Trade-Offs of the Compact City in Peri-Urban Planning Across European City Regions. European Planning Studies 21(4): 473-497, doi: 10.1080/09654313.2012.722927

WHO World Health Organization 2012. Health Indicators of sustainable cities in the Context of the Rio+20 UN Conference on Sustainable Development. WHO/HSE/PHE/7.6.2012f, 2012

Wolch, JR., Byrne, J., Newell, JP. 2014. Urban green space, public health, and environmental justice: the challenge of making cities ‘just green enough’. Landscape and Urban Planning 125: 234-244

Wolff, M., Haase, D. 2019. Mediating Sustainability and Liveability—Turning Points of Green Space Supply in European Cities. Frontiers in Environmental Science 7(61), doi: 10.3389/fenvs.2019.00061

Wüstemann, H., Kalisch, D., Kolbe, J. 2017. Access to urban green space and environmental inequalities in Germany, Landscape and Urban Planning 164: 124-131

Zasada, I., Loibl, W., Berges, R., Steinnocher, K., Köstl, M., Piorr, A., Werner, A. 2013. Rural–urban regions: a spatial approach to define urban–rural relationships in Europe. In: Nilsson, K., Pauleit, S., Bell, S., Aalbers, C., Nielsen, TS. (eds.) Peri-urban futures: scenarios and models for land use change in Europe. Springer, Heidelberg/New York/Dordrecht/London, 45–68

Annex

Figure S1: Proximity to green spaces across Europe 2012 for Non-Urban Green (A) and Urban Green (B).

Figure S2: Cumulative population share located within a given proximity to NUG of up to 30km. (A) Country profiles are grouped by region; (B) Dendogram of the similarity of country profiles.

Figure S3: Ratio of proximities between NUG and UG as an expression of the potential of a given green type to meet demand.