Ecological Indicators 93 (2018) 1–12

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

The impact of different urban dynamics on green space availability: A multiple scenario modeling approach for the region of Munich, Germany

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ARTICLE INFO

Keywords:
Urban dynamics
Green space availability
Scenario modeling
Housing demand
Urban spatial structure
Urban growth form

ABSTRACT

Green spaces can mitigate the negative impacts of urbanization and improve the overall quality of life of urban residents, but the availability of green spaces has been extensively influenced by urban dynamics. In this study, multiple scenarios were developed for one of the fastest and most dynamically growing urban regions in Germany, Munich, with respect to the following three dimensions: housing demand (high, medium or low), urban spatial structure (monocentric or polycentric) and urban growth form (sprawl, compact sprawl or compact). By using per capita green space (PCGS) and the share of the population with access to green spaces (SPAGS) as indicators, the availability of green spaces under different scenarios and the tradeoffs between the two indicators were analyzed at the levels of both regional and sub-regional zones. Our results show that, without effective greening policies, there were different degrees of decline in green space availability in most of the selected scenarios, although scenarios that showed urban shrinkage did result in new green space development. Higher housing demand places more pressure on green space availability at both levels, and the two green space indicators perform better in the polycentric urban spatial structure scenario than in the monocentric scenario. However, one must consider the tradeoffs between the two indicators to define the most advisable urban growth form. The results also highlighted that it is difficult to find a single growth form that performs best in all different zones. Thus, this novel and straightforward scenario approach allows both urban and regional planners to consider the different impacts of urban dynamic scenarios on green space availability and to propose planning strategies adapted to different sub-regional zones.

1. Introduction

Simulating and predicting urban dynamics can improve our understanding of the dynamic processes and possible future of urban systems, which is extremely helpful for implementing sustainable urban development strategies for cities (Haase et al., 2012a; Han et al., 2009). However, exclusively extrapolating from historical trends in urban dynamics into the future may not provide sufficient information for planners to adequately understand the possible future scenarios. Scenario-based modeling, which combines urban dynamic models with narratives of future scenarios or development alternatives, is a powerful tool for planning that addresses the uncertainty of the change in urban land-use patterns by providing plausible, descriptive narratives or pathways to the future, especially when supported by visual outputs such as maps (Cowling et al., 2008; Larondelle et al., 2016). When applying this approach, it is important to consider that scenarios must be effectively translated into modeling language and must logically represent the uncertainties associated with probable futures. Moreover, engaging local and regional stakeholders in scenario development plays an important role in creating, maintaining and progressively improving the relevance, consistency and usefulness of scenarios as planning tools based on local expertise (Reed et al., 2013).

A growing body of literature has frequently discussed three dimensions that influence the regional dynamics of urban systems: housing demand, urban spatial structure and urban growth form. In many cases, the need to accommodate more residents is the main driver of urban growth (Seto et al., 2011). Additionally, it has also been reported that a larger number of households will also intensify land consumption for housing due to an increase in per capita living space, resulting in urban growth even when population sizes are stable or declining (Haase et al., 2013; Liu et al., 2003). Therefore, housing demand, which is represented by the increase in the number of

Abbreviations: PCGS, per capita green space; SPAGS, the share of the population with access to green spaces

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https://doi.org/10.1016/j.ecolind.2018.04.058
Received 5 December 2017; Received in revised form 22 April 2018; Accepted 23 April 2018
1470-160X/

households rather than population growth, can directly affect the extent of urban growth and new land consumption around cities (Nuissl et al., 2009).

The formation of urban spatial structure can be viewed as a dynamic process, during which urban activities are distributed into urban forms through development (Wu and Yeh, 1999). Among various urban spatial structure models used in planning, the polycentric model, which applies to urban systems with multiple functionally networked centers of residence, employment and services, has frequently been debated as an alternative to the monocentric model, in which an urban area is dominated by a central city (Meijers and Romein, 2003). The concept of polycentric urban systems is considered to be more sustainable, more equitable and more capable of reducing the negative impacts of urban dispersion than the monocentric urban system (EEA, 2006; Shaw and Sykes, 2004).

Current debates concerning urban growth forms have generally focused on the contrast between "sprawl" and "compact growth". Urban sprawl has been criticized as unsustainable for a number of reasons, including the non-efficient use of resources, e.g., land and energy (Haaland and van den Bosch, 2015); landscape fragmentation and biodiversity loss (Sushinsky et al., 2013; Troupin and Carmel, 2016); related environmental problems (Haase and Nuissl, 2007; La Greca et al., 2011; Martins, 2012); and last but not least, increasing social inequality (Frenkel and Israel, 2017). In addressing these issues, the concept of compact growth or the compact city, which is characterized by high-density and mixed-use urban development (Milder, 2012), has been extensively discussed as an alternative form to counteract these negative effects of urban sprawl and excessive land use. However, compact growth also has its disadvantages, such as feelings of overcrowding, increasing levels of air pollution and heat stress, and traffic noise and traffic jams, that result in a lower quality of life and a considerable lack of urban green and open spaces in increasingly dense urban areas and central city districts (Chen et al., 2008; Haaland and van den Bosch, 2015; Pauleit et al., 2005).

By supporting biodiversity and providing ecosystem services, green spaces can mitigate the negative impacts of urbanization and improve the quality of life of urban residents and are thus as a fundamental part of sustainable urban development (Chiesura, 2004; Jim, 2004). Vital ecosystem services delivered by green spaces include, among others, air purification (Jim and Chen, 2008a), temperature mitigation (Rahman et al., 2017), noise reduction (Margaritis and Kang, 2017), carbon storage (Strohbach and Haase, 2012), flood regulation (Zölch et al., 2017), recreational services (He et al., 2016), and biodiversity conservation (Nielsen et al., 2014). Furthermore, green spaces also provide valuable cultural services, such as by offering meeting places for local residents (Bijker and Sijtsma, 2017) and potentially improving the sense of safety of a population (Kuo et al., 1998).

The availability of green spaces is extensively influenced by the dynamics of urban development (Zhao et al., 2013), but most recent studies have focused on only the impacts of different urban growth forms. For instance, McDonald et al. (2010) examined the loss of open space in all 274 metropolitan areas in the US between 1990 and 2000 and indicated that 1.4 million ha of open space were lost due to urban expansion. However, several other studies have indicated that compact urban growth could lead to a general loss of urban green spaces in residential areas as well. Fuller and Gaston (2009) reported that green space coverage declined mildly as population density increased, and compact cities showed very low per capita green space across 386 cities in Europe.

Although it is known from the literature that public green space has increased during urban growth in certain cases, this has mainly been related to the overall increase in the total city area and the implementation of effective greening policies (Tan et al., 2013; Zhao et al., 2013), without which it is very likely that urban sprawl will pose enormous threats to green spaces in the countryside while compact growth will lead to reduced urban green spaces within urban areas (Nuissl et al., 2009). In other words, some green spaces are always lost during urban growth regardless of the adopted growth form (Zhao et al., 2013). However, relative studies have so far focused on either sprawling or compact growth, while comparative studies that consider the impact of both urban growth forms on green space availability are rare. Moreover, previous studies have mainly been carried out at the city level and thus have lacked a systematic analysis of the impacts of different development trends and urban dynamics on the availability of green spaces at the regional level.

In this context, this study seeks to develop and apply a multiple scenario modeling approach to systematically and quantitatively assess the potential impacts of different population and household dynamics on the urban forms and green spaces in the region of Munich, an urban area under high land development pressure. To this end, multiple urban dynamic scenarios are developed that account for the three previously mentioned dimensions that influence urban dynamic processes including housing demand, urban spatial structure, and urban growth form. Then, the impacts of different urban dynamic scenarios on green spaces are comparatively assessed in terms of green space availability. The main objectives are (1) to investigate how green space availability varies across different urban dynamics, (2) to examine the impacts of different urban dynamics on green space availability at the regional level and (3) to identify the differences between these impacts in different sub-regional zones.

2. Materials and methods

2.1. Study area and data sources

According to the Bavarian state development scheme, the region of Munich, which is composed of the city of Munich and 186 municipalities in eight administrative districts ("Landkreise"), is one of the 18 planning regions in Bavaria in southern Germany (Fig. 1). With a total area of 5504 km^2 and a population of 2.85 million in 2015, this region is regarded as one of the fastest growing (with an average annual population growth rate of approximately 1.0% over the past decade) and most economically competitive regions in Europe. As the major city of this region and the capital of the state of Bavaria, Munich is the third largest, and one of the most populous, cities in Germany, with approximately 1.45 million residents and an average population density of approximately 4668 inhabitants per km^2 in 2015 (Bavarian State Office for Statistics, 2015). The Bavarian State Office for Statistics has projected that the population will continuously increase to almost 3.2 million by 2034, which will consequently contribute to urban growth both near the city of Munich and throughout the region.

In this region, the present urban spatial structure clearly follows a monocentric model with the city of Munich at its center (Goebel et al., 2007), but this region has the potential for polycentric development due to the presence of several subcenters, as shown in Fig. 1, that are defined in the regional plan (RPV, 2005). Regional land cover data for the years 2003 and 2013 have been derived from high-resolution aerial photography, which offers much more detailed information about the distribution of and changes in different land uses. In this study, the settlement areas were classified into high-density settlements, such as multistory housing and multistory blocks, and low-density settlements, such as row housing, single-family housing and detached houses.

In this study, green spaces comprised the following land-use classes: "parks and green spaces", "allotment gardens", "cemeteries" and "forests" (as shown in Fig. 1). Other land use classes, such as "arable land", "grassland" and "wetland", that could potentially serve as green spaces were excluded from our analysis due to their relatively low recreational value (Kabisch et al., 2016). The "sports and leisure facilities" class (e.g., football stadiums, tennis courts, and golf courses) was also excluded because of the associated low vegetation coverage and lack of public accessibility. In the Urban Core Zone, the main types of green space are large parks and the continuous greenbelt along the Isar River,