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Peri-urban farmland included in green infrastructure strategies promotes transformation pathways towards sustainable urban development

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ABSTRACT

Urbanization and agricultural land use are two of the main drivers of global changes with effects on ecosystem functions and human wellbeing. Green Infrastructure is a new approach in spatial planning contributing to sustainable urban development, and to address urban challenges, such as biodiversity conservation, climate change adaptation, green economy development, and social cohesion. Because the research focus has been mainly on open green space structures, such as parks, urban forest, green building, street green, but neglected spatial and functional potentials of utilizable agricultural land, this thesis aims at fill this gap.

This cumulative thesis addresses how agricultural land in urban and peri-urban landscapes can contribute to the development of urban green infrastructure as a strategy to promote sustainable urban development. Therefore, a number of different research approaches have been applied. First, a quantitative, GIS-based modeling approach looked at spatial potentials, addressing the heterogeneity of peri-urban landscape that defines agricultural potentials and constraints. Second, a participatory approach was applied, involving stakeholder opinions to evaluate multiple urban functions and benefits. Finally, an evidence synthesis was conducted to assess the current state of research on evidence to support future policy making at different levels.

The results contribute to the conceptual understanding of urban green infrastructures as a strategic spatial planning approach that incorporates inner-urban utilizable agricultural land and the agriculturally dominated landscape at the outer urban fringe. It highlights the proposition that the linkage of peri-urban farmland with the green infrastructure concept can contribute to a network of multifunctional green spaces to provide multiple benefits to the urban system and to successfully address urban challenges. Four strategies are introduced for spatial planning with the contribution of peri-urban farmland to a strategically planned multifunctional network, namely the connecting, the productive, the integrated, and the adapted way. Finally, this thesis sheds light on the opportunities that arise from the integration of the peri-urban farmland in the green infrastructure concept to support transformation towards a more sustainable urban development. In particular, the inherent core planning principle of multifunctionality endorses the idea of co-benefits that are considered crucial to trigger transformative processes.

This work concludes that the linkage of peri-urban farmland with the green infrastructure concept is a promising action field for the development of new pathways for urban transformation towards sustainable urban development. Along with these outcomes, attention is drawn to limitations that remain to be addressed by future research, especially the identification of further mechanisms required to support policy integration at all levels.

ZUSAMMENFASSUNG

Urbanisierung und Landwirtschaft zählen zu den wesentlichen Faktoren des globalen Wandels mit Auswirkungen auf Ökosystemleistungen und menschliches Wohlergehen. Grüne Infrastruktur gilt als ein neuartiger Ansatz in der räumlichen Planung zur nachhaltigen Stadtentwicklung und um Begegnung von Herausforderungen wie den Schutz der biologischen Vielfalt, Anpassung an den Klimawandel, Entwicklung einer nachhaltigen Wirtschaft und zur des sozialen Zusammenhalts. Da ein Forschungsschwerpunkt bislang auf Freiraumstrukturen wie Parks, städtischen Wäldern, Gebäudebegrünung und Straßengrün lag, die räumlichen und funktionalen Potenziale landwirtschaftlicher Flächen unberücksichtigten, soll diese Arbeit hierzu einen Diskussionsbeitrag leisten.

Diese kumulative Abschlussarbeit befasst sich mit der Frage, wie stadtnahe Landwirtschaftsflächen zur Entwicklung urbaner grünen Infrastrukturen, als Strategie zur Förderung einer nachhaltigen Stadtentwicklung beitragen können. Hierzu wurden verschiedene Forschungsansätze angewendet. Zunächst erfolgte ein quantitativer, GIS-basierter Modellierungsansatz, der sich mit den räumlichen Möglichkeiten und Grenzen befasst. Zweitens wurde ein partizipatorischer Ansatz verfolgt, der Funktionen und Nutzen aus Sicht verschiedener Interessenvertreter evaluiert. Schließlich wurde eine Evidenzsynthese durchgeführt, um den aktuellen Stand der Forschung hinsichtlich einer evidenzbasierten Politikgestaltung zu bewerten.

Die Ergebnisse tragen zum konzeptionellen Verständnis urbaner grüner Infrastrukturen als strategischen raumplanerischen Ansatz bei, der Landwirtschaft mit einbezieht. Sie unterstützen die These, dass peri-urbane Landwirtschaftsflächen mit dem grünen Infrastrukturansatz zur Entwicklung eines multifunktionalen Freiraums beitragen und somit städtische Herausforderungen begegnen können. Es werden vier Strategien für eine Raumplanung vorgestellt, die sich für die Planung eignen. Schließlich beleuchtet diese Arbeit, welche Möglichkeiten sich in der Verknüpfung peri-urbaner Landwirtschaftsflächen mit dem Grüne Infrastrukturansatz für Transformationsprozesse bieten, um eine nachhaltige Stadtentwicklung zu unterstützen. Insbesondere das Kernplanungsprinzip der Multifunktionalität unterstützt die Idee zusätzlicher Nebeneffekte – sogenannte Co-Benefits –, die als einen wichtigen Auslöser transformativer Prozesse gelten.

Die Arbeit kommt zu dem Schluss, dass sich durch die Berücksichtigung peri-urbaner Landwirtschaftsflächen im Grüne Infrastrukturansatz vielversprechende Handlungsfelder und Entwicklungspfade für eine nachhaltige Stadtentwicklung bieten. Neben diesen Ergebnissen wird auf die Grenzen aufmerksam gemacht, die von der künftigen Forschung noch angegangen werden müssen, insbesondere die Identifizierung weiterer Mechanismen, die zur Unterstützung der politischen Integration auf allen Ebenen erforderlich sind.

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1. INTRODUCTION

1.1. RESEARCH BACKGROUND

The ecological planetary boundaries are under threat, with the transgression of safe limits of four of nine ecological boundaries (Rockström et al., 2009; Steffen et al., 2015). As illustrated by the 'Doughnut of Social and Planetary Boundaries' (figure 1) there are further shortfalls regarding social dimensions (Raworth, 2012; 2017), related to the United Nations 2030 Agenda adopted in 2015 and its Sustainable Development Goals (United Nations, 2015).

Fig. 1. The Doughnut of Social and Planetary Boundaries with ecological overshots and social shortfalls in red color (based in Steffen et al., 2015 and Raworth, 2017).

Land use is one of the primary drivers of global changes with effects on ecosystem functions and human wellbeing (MEA, 2005). Two very recent global assessments present compelling evidence of the effects of land use and the need for sustainable land management, underpinning the urgency of the current state and trends and the need for change. The first of these, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), observes worldwide deterioration of “nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services” (IPBES, 2019). The second, the special report on ‘Climate Change and Land’ of the Intergovernmental Panel on Climate Change (IPCC) urges “urgent action to stop and reverse the over-exploitation of land resources” and to “buffer the negative impacts of multiple pressures, including climate change, on ecosystems and society” (IPCC, 2019). Crucial factors, identified by both studies, are urbanization and unsustainable agricultural intensification.

Expansion of agricultural land use and unsustainable intensification of agricultural practices are among the main direct drivers of land degradation and loss of biodiversity globally (IPBES 2018). The impact of modern agriculture on ecosystems, biodiversity and human wellbeing has been widely discussed (e.g., Tilman, 1999; Kremen et al., 2002; Foley et al., 2005; Hooper et al., 2005; Stoate et al., 2009; EEA, 2013) and conflicts are considered to be accelerating because of increased food demand, climate change, and resource and land competition (Godfray et al., 2010; Wheeler and Braun, 2013). In the European Union from 1975 to 2015, the percentage of agricultural land of the total land area dropped from 52% to 43% (World Bank Data 2019a) while the population increased from 454 million to 509 million (World Bank Data 2019b). Agricultural intensification and global trade, although leading to an increase in food provision, have also negatively affected “many of nature’s other regulating contributions to people” (IPBES, 2018a). Nevertheless, promising approaches suggest reconciling agricultural food production systems with the conservation of biodiversity and promotion of ecosystem services for human benefit (e.g., Jackson and Jackson, 2002; Rosenzweig, 2003; Clements and Shrestha, 2004; Scherr and McNeely, 2007; Pollock et al., 2008; Foley et al., 2011; Tscharntke et al., 2012; Gliessman, 2015). Sustainable agricultural pathways can be roughly categorized by the two different concepts of sustainable agricultural intensification (SAI) and agroecological intensification (AEI) (cf. Mockshell and Kamanda, 2018).

On the other hand, urbanization is an important driver of environmental change at local and global scales, causing habitat loss and fragmentation, over-exploitation of natural resources, pollution and climate change (e.g., Grimm et al., 2008; Seto et al., 2011; 2012; Elmquist et al., 2013), as well as effects at the peri-urban scale through urban-rural linkages (Piorr et al., 2011). In turn, cities are vulnerable to these changes because of their effect on human health and well-being of city dwellers (EEA, 2018b). Well-known examples are air pollution (EEA 2018c) and climate change (e.g., EEA, 2017b; Rosenzweig et al., 2018). In Europe, urbanization is considered to be the main cause of land use change (Eigenbrod et al., 2011). In 2018, approximately 75% of the population lived in urban areas (worldwide 55%). This is expected to reach about 85% by 2050 (worldwide 68%) (UN DESA, 2019). Urban growth is driven by different dynamics and differs markedly between less developed regions and the more developed regions and also across and within countries (Seto et al., 2013). European cities evolve in a variety of phases and stages as a complex of functional, morphological and structural changes (Antrop, 2004). Their development relies on diverse drivers (cf. EEA, 2006; EEA, 2016) and can be characterized as rather 'mature urban structures', developed over time, "adapting to the changing needs of the people and to technological developments" (WBGU, 2016). Well-managed urban growth needs to take into account sustainable development of all three dimensions – social, economic, and environmental – "to maximize the benefits of high levels of density while minimizing environmental degradation and other potential adverse impacts of a growing number of city dwellers" (UN DESA, 2019).

As a consequence of these threats and challenges posed by urbanization and agricultural land use, both systems belong to two of the six main fields of society's transformation towards sustainable development (WBGU, 2011; TWI2050; 2018; Sachs et al., 2019) needed to achieve the United Nations 2030 Agenda (figure 2).

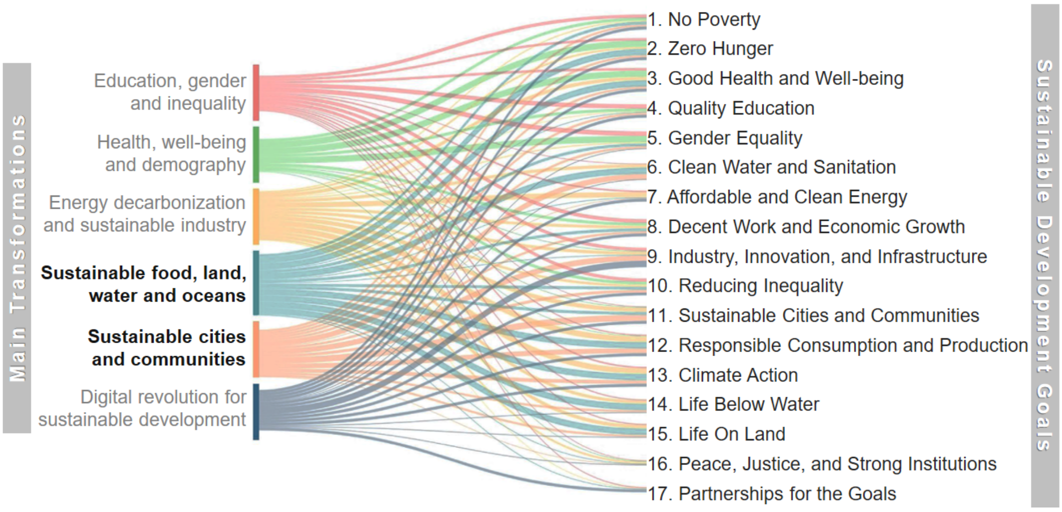


Fig. 2. Sankey diagram illustrating contributions of the six main fields of society's transformation towards the Sustainable Development Goals to which belong sustainable agricultural food systems and sustainable cities (adapted from Sachs et al., 2019).

Moreover, both systems can be linked in subnational regional settings – in positive as well as negative ways. Urban and peri-urban agriculture (UPUA) offer promising pathways to promote transformation towards sustainable development (IAASTD, 2009; IPCC, 2019). On the other hand, urban growth leads to land consumption at the cost of productive agricultural land across Europe (Gardner, 1996; Döös, 2002; Bren d'Amour et al., 2017). The depletion of farmland as a result of land conversion due to urban growth is considered one of the challenges within the transformation action field towards sustainable urban land use (WBGU, 2016).

A number of strategic spatial planning approaches evolved since the 1960s to tackle these challenges and to promote sustainable land use development in urban areas (Albrechts, 2004; Healey, 2006). The concept of Green Infrastructure (GI) has emerged as a spatial planning approach that contributes to sustainable development and to cope with urban sprawl (Benedict and McMahon, 2002; Walmsley, 2006). It is being promoted as a promising contribution to the development of resilient cities and sustainable urban transformation (IASS, 2013; WBGU, 2016), gaining increased attention in scientific research recently.

The ideas inspiring this Ph.D. thesis were developed during the GREEN SURGE research project – Green Infrastructure and Urban Biodiversity for Sustainable Urban Development and the Green Economy (2013-2017), funded by the European Commission Seventh Framework Programme (Pauleit et al., 2019). Some of the first deliverables of this project revealed that the evidence base addressing agricultural land in regard to GI objectives in urban contexts – Urban Green Infrastructure (UGI) – is limited in comparison with other urban green space types (Haase et al., 2014; Cvejić et al., 2015). Still, many open spaces in European cities are dominated by agricultural land, thus making it a relevant spatial factor that needs to be considered.

Against this background, the questions this thesis seeks to answer are if and how UPUA can contribute to the basic conception of GI as an "interconnected network of green spaces that conserves natural ecosystem values and functions and provides associated benefits to human populations" to provide an ecological framework "for environmental, social and economic sustainability" (Benedict and McMahon, 2002).

Before further defining the thesis' research questions and objectives, an overview of the state of knowledge will be given, looking at GI and agriculture in functional urban areas in order to address potential links and current knowledge gaps that need to be filled so that these links may be realized.

1.2. CONCEPTUAL BACKGROUND

1.2.1. GREEN INFRASTRUCTURE PLANNING

Although the term 'Green Infrastructure' (GI) is relatively new, its ideas are related to earlier concepts of urban planning (Wright, 2011) and also to biodiversity conservation (Ahern 2007). It can be dated back into the 19th century's emerging greenway approach and garden city movement (Benedict and McMahon, 2006). Since the concept of GI emerged in the United States in the late 1990's – to tackle urban sprawl – it evolved very dynamically on different scales, emphasizing various objectives (Mell, 2017; cf. Kambites und Owen 2006; Tzoulas et al., 2007; Mell 2010; Wright, 2011; Rouse und Bunster-Ossa 2013; Sinnett et al., 2015). For instance, in the United Kingdom, it has been further developed to enhance the green belts approach at the peri-urban fringe (Amati and Taylor, 2010; Thomas and Littlewood, 2010). Despite different conceptualizations and definitions – being as manifold as "there are authors working on the concept" (Mell, 2010) –, GI's aims are commonly understood "to create multifunctional networks of green spaces" (Pauleit et al., 2017), with connectivity and multifunctionality as two inherent key principles.

GI comprises a strategically planned network, designed to connect different elements to a multifunctional system (Benedict and McMahon, 2006). It relies on 'hubs' to anchor the system, 'links' as connections and 'sites', which are smaller areas, that may not be necessarily attached but complement the system (figure 3).

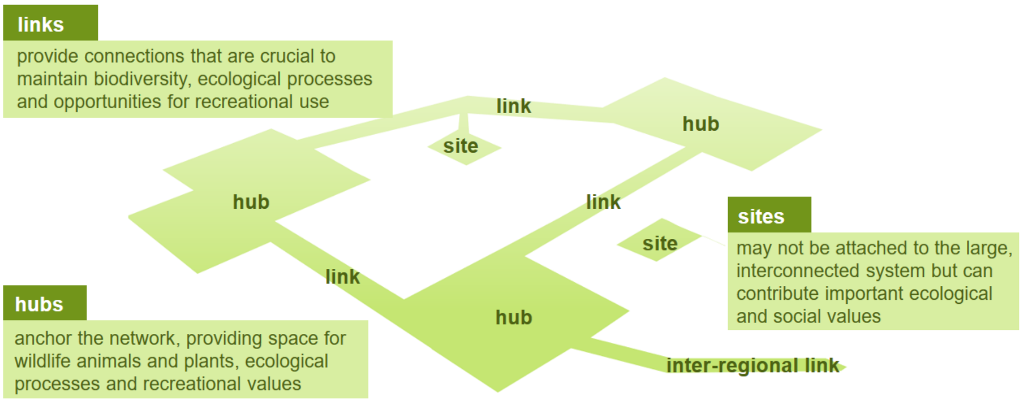


Fig. 3. The GI network consisting of 'hubs', 'links' and 'sites' that connects different elements i.e., ecosystems and landscapes (adapted from Benedict and McMahon, 2006).

A recent milestone to promote GI in Europe was the adoption of the European GI Strategy by the European Commission in 2013 as part of the six main targets of the EU Biodiversity Strategy to 2020 (European Commission, 2011). This strategy defines green infrastructure as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission, 2013). It extends the focus of species and habitat conservation of Natura2000 and reflects a holistic approach to natural areas and other open spaces in urban and non-urban surroundings, taking into account a variety of society's demands, contributing to societal health, human well-being, and the green economy (cf. Sundseth and Sylwester, 2009).

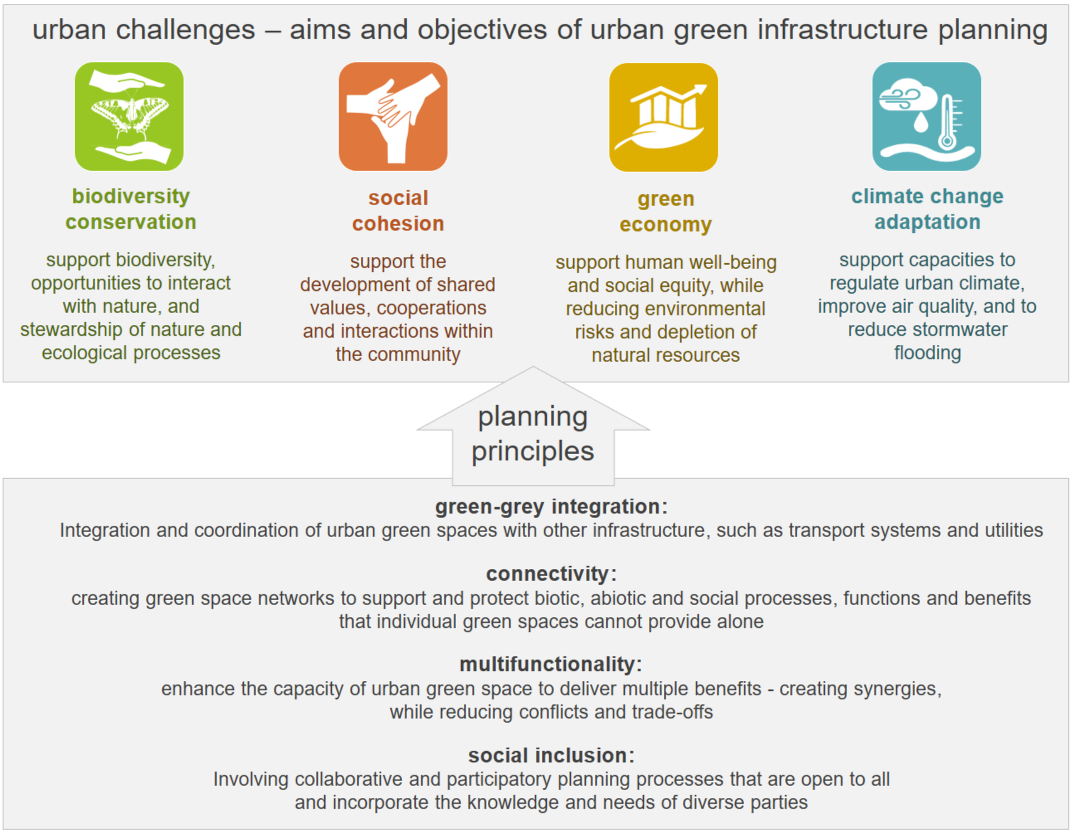
GI planning can be applied to various spatial scales, which could ideally nested into each other (Ahern, 2007; Pauleit et al., 2019a). At the upper level, these comprise transnational approaches, such as the EU-level green and blue infrastructure projects

(European Commission, 2019) or national frameworks such as the federal GI concept of Germany (BfN, 2017). At the interregional and regional levels, these can be concepts and plans of multifunctional, integrated biotope networks as well as open space systems, like the Emscher Landscape Park in the Ruhr Area (RVR, 2016).

Urban GI (UGI) planning aims to develop multifunctional networks at different urban scales – from urban regional scale to neighborhood scale – interlinked with GI planning at the surrounding landscape scale (Hansen et al., 2016). Hence, UGI can be diverse, consisting of a mosaic of different green spaces, from regional-scale objects, such as, forests, urban and peri-urban agricultural land and waters, to local-scale objects, like parks, gardens, green roofs, greened walls or street trees (Bartesaghi Koc et al., 2016). Within GREEN SURGE, a UGI typology has been developed (Cvejić et al., 2015) consisting of 44 different types, grouped in eight classes (figure 4).

Fig. 4. UGI typology as developed by the GREEN SURGE project (based on Cvejić et al., 2015).

Accordingly, UGI planning can be defined as "a strategic planning approach that aims to develop networks of green and blue spaces in urban areas, designed and managed to deliver a wide range of ecosystem services and other benefits at all spatial scales." (figure 5) (Hansen et al., 2016). It is a promising approach and hence contributing to policy objectives for sustainable urban development (Lafortezza et al., 2013; Mell, 2017; Pauleit et al., 2017). It responds to environmental and social challenges, such as biodiversity conservation (e.g., Müller et al., 2010; Elmqvist et al., 2013), climate change adaptation (e.g., Bowler et al., 2010; Demuzere et al., 2014; Liu et al., 2015), green economy development (e.g., Simpson and Zimmermann, 2013; Andersson et al., 2016), and social cohesion (e.g., Thompson, 2002; Peters et al., 2010; Haase et al., 2017). Davies et al. (2015) summarize several vital principles for successful UGI planning and implementation from the literature. Besides the two main principles of connectivity and multifunctionality, are the integration and coordination of urban green with grey infrastructure, multiscale planning, as well as the design of strategic, cooperative and socially inclusive planning processes (cf. Benedict and McMahon, 2006; Kambites and Owen, 2006; Ahern, 2007; Pauleit et al., 2011). As an integrated cross-sectoral spatial planning approach, comprising a number of different landscape functions and services successful UGI planning needs interdisciplinary approaches and communication strategies to raise understanding and appreciation of ecological processes, functions and associated human benefits among different stakeholders involved (cf. Derkzen et al., 2017; Buijs et al., 2019; Jagt et al., 2017; Ferreira et al., 2020).



support biodiversity, opportunities to interact with nature, and stewardship of nature and ecological processes

support the development of shared values, cooperations and interactions within the community

support human well-being and social equity, while reducing environmental risks and depletion of natural resources

support capacities to regulate urban climate, improve air quality, and to reduce stormwater flooding

green-grey integration:
Integration and coordination of urban green spaces with other infrastructure, such as transport systems and utilities

connectivity:
creating green space networks to support and protect biotic, abiotic and social processes, functions and benefits that individual green spaces cannot provide alone

multifunctionality:
enhance the capacity of urban green space to deliver multiple benefits - creating synergies, while reducing conflicts and trade-offs

social inclusion:
Involving collaborative and participatory planning processes that are open to all and incorporate the knowledge and needs of diverse parties

Fig. 5. Scheme illustrating the understanding of UGI planning as conceptualized by the GREEN SURGE project (adapted from Hansen et al., 2017; based on European Commission, 2013; Pauleit et al., 2011; Benedict and McMahon, 2006; Kambites and Owen, 2006).

Meanwhile, effectiveness, potentials, and limitations of UGI planning approaches have been examined in-depth, based on several case studies across Europe (Hansen et al., 2016; Grădinaru and Hersperger, 2019). Furthermore, examples suggest that utilizable agricultural land can be an integral part of UGI, as seen in Barcelona (Consorti Parc Agrari del Baix Llobregat, 2004), Frankfurt (Sterly and Mathias, 2016; Knickel et al., 2016) or Milan (Regione Lombardia, 2010).

However, the focus of research on UGI planning has mainly been on green urban structures, such as parks, urban forest, building and street green, but has neglected spatial and functional potentials of utilizable agricultural land (cf. Breuste et al., 2015; Cvejić et al., 2015; Bartesaghi et al., 2016; Lee and Song, 2019; Panagopoulos, 2019; Pauleit et al., 2019). Consequently, there is a knowledge gap in how urban and peri-urban utilizable agricultural land can contribute to UGI. This raises questions about whether utilizable agricultural land can contribute to the development of multifunctional green space networks based on the UGI conception and its planning principles. Furthermore, it needs to be addressed how spatial planning under the GI conception can look incorporating utilizable agricultural land.

With this in mind, the next section will give an overview of the current state of knowledge about agriculture in functional urban areas.

1.2.2. AGRICULTURE IN FUNCTIONAL URBAN AREAS

'Peri-urban' landscape is the transition from urban to rural as "the area between urban settlement areas and their rural hinterland [… that] can include towns and villages within an urban agglomeration" (Piorr et al., 2011). Together with the urban, it builds the functional urban area (Ravetz et al., 2013). The peri-urban landscape consists of a "heterogeneous mosaic of 'natural' ecosystems, productive 'agro-' ecosystems, and 'urban' ecosystems affected by the material and energy flows, demanded by the urban and rural systems" (Allen, 2003). It can be characterized by a dynamic of chaotic development effected by population growth and rapid urbanization, along with the loss of agricultural and natural land (Geneletti et al., 2017). Several studies have addressed services, disservices, trade-offs and conflicts in the peri-urban landscape (e.g., Busck et al., 2006; Piorr et al., 2011; Nilsson et al., 2013; Radfort et al., 2013; Westerink et al., 2013; Primdahl et al., 2013; Colucci et al., 2017; La Rosa et al., 2018; Phearson et al., 2018; Wilhelm and Smith, 2018). Despite shortcomings and challenges for spatial planning (Dunk et al., 2011; La Rosa et al., 2018), the value of peri-urban landscapes in providing essential ecosystem services of relevance for the sustainability of cities is increasingly being recognized (Scott et al., 2013; Primdahl, 2014; Colucci, 2015; Hedblom et al., 2017).

Agricultural land dominates European peri-urban landscapes (figure 6). However, productive agricultural land across Europe is being diminished by urban growth (Gardner, 1996; Döös, 2002; Bren d'Amour et al., 2017). Between 2000-2012 more than 75% of all areas that changed to artificial surfaces were farmland (arable land, permanent crops, pastures), compared to 13–14% forests and transitional woodland shrub (EEA, 2017a, EEA, 2018a).

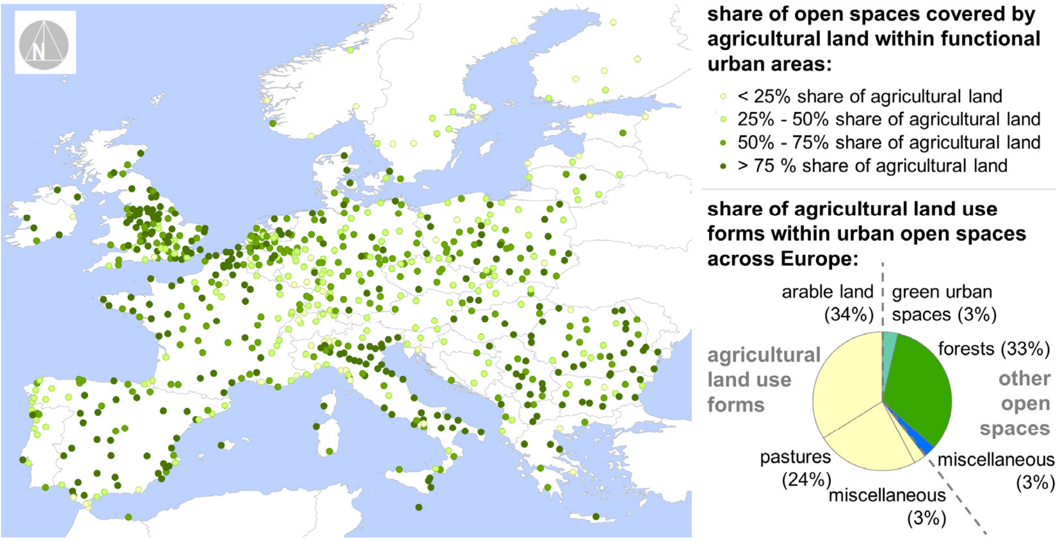


Fig. 6. Share of functional urban areas by agricultural land use. Calculation based in Urban Atlas data (EEA 2012).

Agriculture in the peri-urban landscape can be very diverse, depending on site-specific conditions, potentials and constraints, such as soil, climate, water and topography, leading to a wide range of productivity – ranging from low to high productive farmland. Furthermore, agricultural business strategies can be roughly divided into two main categories (Sanz Sanz et al., 2018). They may be independent of the urban context, such as farms producing goods for the international market rather than for the urban market, or they can be functionally linked to the city. The latter ones can be assigned to UPUA – as agriculture “within (intra-urban) or on the fringe (peri-urban) of a town, a city, or metropolis that grows or raises, processes and distributes a diversity of food and non-food products, (re-)uses largely human and material resources, products and services found in and around that urban area, and in turn supplies human and material resources, products and services largely to that urban area” (Mougeot, 2000). As mentioned earlier, UPUA is linked to the hopes and expectations of promising solutions for sustainable development (see chapter 1.1). UPUA is considered a significant ingredient of urban metabolism (e.g., Kennedy et al., 2007; Kulak et al., 2013; Goldstein et al., 2016) and evidence suggests that UPUA “can contribute to improving urban food security, reducing greenhouse gas emissions, and adapting to climate change impacts” (IPCC, 2019).

Besides the contributions of agriculture to sustainable development in multifunctional rural landscapes (Helming and Wiggering, 2003) UPUA has been a research subject of multifunctionality at the farm level, providing many social, economic and environmental functions (e.g., Van Veenhuizen and Danso, 2007; Pearson et al., 2010; Zasada, 2011; Viljoen and Bohn, 2014; Zeeuw and Drechsel, 2015; Rogus and Dimitri, 2015; Goldstein et al., 2016; Olsson et al., 2016; Lohrberg et al., 2016, Piorr et al. 2018). UPUA has gained attention from researchers, stressing it explicitly in the context of UGI (e.g., Dunn, 2010; La Greca et al., 2011; La Rosa and Privitera, 2013; Timpe et al., 2016). Farming business models that maintain cultural heritage, contribute to the conservation of agro-diversity and biodiversity, and are linked with the marketing of high-value products (including the provision of other cultural and social values), are now understood "as good examples of agriculture-based green infrastructure within metropolitan areas" (Lohrberg et al., 2016). However, research tended to focus on small-scale activities such as rooftop, allotment or community gardening (e.g., Horst et al., 2017; Lovell, 2010; Ackerman, 2012; Mees and Stone, 2012; Whittinghill and Rowe, 2012; Drake, 2013; Hartig et al., 2014; Lin et al.; 2015; Aerts et al., 2016: Martin et al., 2017; Raymond et al., 2017; Russo et al., 2017; Artmann and Sartison, 2018), suggesting 'edible green infrastructure' as a nature-based solution that combines food production systems with positive effects on the urban environment.

Nevertheless, some research focusing on UPUA point to linkages to UGI objectives, such as sustainable economic growth (e.g., Pölling and Born 2015), climate change mitigation (Lipper et al., 2014), social functions (Zasada, 2011; Brinkley, 2012), recreational values, (e.g., Ingersoll 2013; Zasada et al. 2013), and urban climate (Ren et al., 2011; Scherer et al., 1999). From this, it appears that besides the existing knowledge about multifunctionality on the farm level its consideration at the landscape level seems to be also worth it.

The integration of utilizable agriculture land into urban spatial planning is not a new idea. It includes ideas such as the Thuenen's concentric rings of agricultural land used to develop agriculture in relation to the central city (von Thünen et al., 1826), the garden cities intended to balance residential housing, industry and agriculture (Howard, 1902), and green belts to protect agricultural land and its values (Amati, 2008). Since the last 20 years again, discussion of modern conceptual ideas has evolved to integrate various forms of UPUA into spatial urban planning and design (e.g., Drescher, 2001; Lohrberg, 2001; Mougeot, 2006; Philips 2013; Viljoen and Bohn, 2014; Timpe, 2017). In addition, several integrative planning approaches and instruments have shown that utilizable agriculture land can play an important role to integrate basic and applied ecology by considering multifunctionality and connectivity, and thus revealing linkages with the UGI planning concept (e.g., Muñoz-Rojas et al., 2015; Landis, 2017; Burton et al., 2019).

Hence, besides the quantitative spatial potentials of utilizable agriculture land in the peri-urban, there are further promising starting points suggesting its suitability for UGI planning (figure 7).

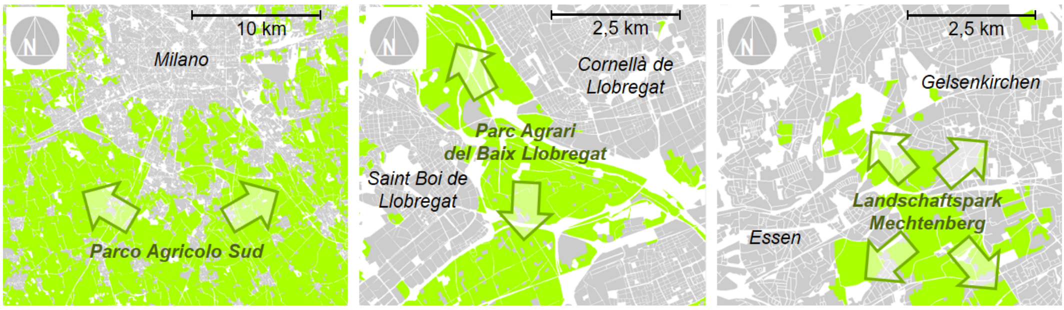


Fig 7. Different spatial distribution of utilizable agricultural land (green color) in urban agglomerations as part of urban green network; Parco Agricolo Sud in Milan as green belt (left), Parc Agrari del Baix Llobregat in Barcelona as green corridor (middle), and Landschaftspark Mechtenberg in Ruhr Region as part of green network (right) (based on Urban Atlas Data, EEA 2012).

To summarize, there is a broad understanding of services and disservices at the peri-urban landscape scale, while looking at utilizable agricultural land, as well as UPUA in particular. Furthermore, there are planning approaches that deal with the particularities and challenges of the peri-urban landscape. However, with regard to UGI planning, some aspects of these approaches appear to be incomplete or not yet robust enough to implement. Hence, a more systematic approach is needed to put current knowledge into the context of UGI planning, which would entail assessing existing evidence concerning the aims and objectives of UGI as well as the identification of knowledge gaps. Furthermore, it is essential to consider multifunctionality at the landscape level to ensure the suitability of UGI as a spatial planning approach. Examining multifunctionality at the landscape level involves looking at landscape heterogeneity and the different site characteristics that define both agricultural potentials and constraints. It also involves developing strategies for network design while making use of synergies in order to minimize trade-offs between competing functions. Moreover, it must take into account all the different stakeholder interests, including the interests of the key actor, the farmer.

1.3. AIMS AND RESEARCH QUESTIONS

The overarching aim of this thesis is to investigate whether peri-urban farmland can contribute to the development of UGI as a strategy to promote sustainable urban development.

The subject, 'peri-urban farmland', is understood here to emphatically include all of the utilizable agricultural land within the functional urban area under consideration. Thus, utilizable agricultural land consists of all forms of extensive and intensive farming, whether assigned to UPUA in the narrow or broader sense.

Importantly, it also includes agricultural land uses that do not intentionally supply (nor do they appear to do so) any resources, products, or services to the urban area.

This thesis addresses the overarching topic by examining the following research questions:

- How can peri-urban farmland support the development of multifunctional green space networks based on the two core GI principles connectivity and multifunctionality?
- Can peri-urban farmland be linked to the UGI conception to develop a strategic planned multifunctional network?
- How can peri-urban farmland as a component of UGI promote pathways of transformation towards sustainable urban development?

1.4. STRUCTURE OF THIS THESIS

Due to these research questions, the following published articles are presented here to discuss these contexts.

Article-I: Farmland – an Elephant in the Room of Urban Green Infrastructure? Lessons learned from Connectivity Analysis in three German Cities. This article investigates the potential contributions of peri-urban farmland to connectivity, as one of the two GI key principles using a quantitative GIS-based analysis of structural connectivity. The study is conducted in functional urban areas of the three largest and expanding cities in the federal state of Bavaria in Southeast Germany, namely Munich, Augsburg, Nuremberg, all three belonging to European Metropolitan Regions[1]. The study uses structural connectivity as a surrogate for functional connectivity, supporting a variety of ecological, social and abiotic processes and functions. It focuses on low-intensity farmland as a site-specific characterization (using habitat suitability modeling), hypothesizing that it offers particular potential for multiple functions.

Article-II: Algorithmic Landscapes meet Geodesign for effective Green Infrastructure Planning – Ideas and Perspectives. This article is an additional methodological excursion and incorporates the habitat suitability modeling approach, as applied in Article-I. It discusses the use of GIS modeling and algorithms to analyze complex ecological interrelations in the landscape. It shows how they help to handle comprehensive environmental data to process them purposefully and to support communication strategies for collaborative GI planning.

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[1] European Metropolitan Regions in accordance with the NUTS level 3 regions that identify metropolitan regions in the European Union (EU); SOURCE: NUTS-2016 (https://ec.europa.eu/eurostat/documents/4313761/4311719/Metro-regions-NUTS-2016.xlsx)

Article-III: A stakeholder Approach, Door Opener for Farmland and Multifunctionality in Urban Green Infrastructure. This article investigates the contribution of peri-urban farmland to multifunctionality, another GI key principle. Using participatory research to involve stakeholder opinions, this approach evaluates multifunctionality qualitatively. The research area is the peri-urban landscape of the European Metropolitan Region of Malmö, Sweden. The study takes into account the heterogeneity of agricultural land and its diversity of site-specific conditions, potentials and constraints, taking into account both: low and high productive farmland.

Article-IV: Integrating farmland in Urban Green Infrastructure planning. An evidence synthesis for informed policymaking. This article conducts a synthesis of evidence based on a comprehensive literature analysis to see if the current state of research supports evidence-based policymaking by arguments that agriculture landscapes can contribute to UGI aims, namely biodiversity conservation, climate change adaptation, green economy development, and social cohesion. A reciprocal approach is applied, evaluating how policymaking at the European level provides a framework to encourage and facilitate UGI development in agriculture landscapes and to address potentials and gaps in evidence-based policymaking that is needed to support transformation.

The structure of this thesis is illustrated in figure 8.

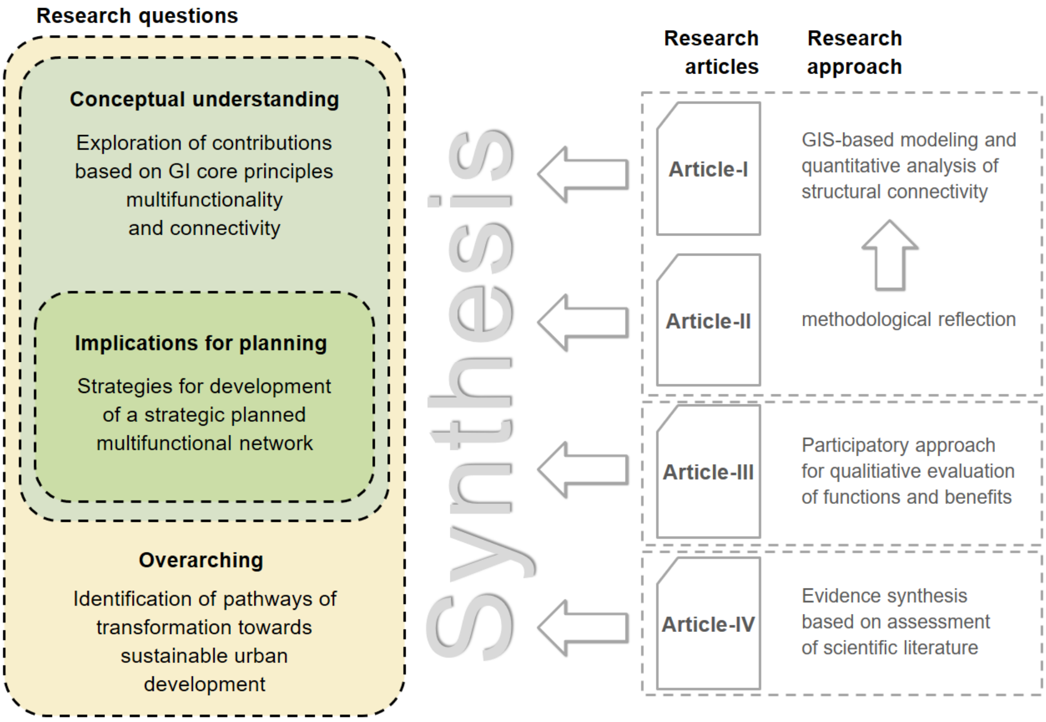

Fig. 8. Structure of the thesis and with research approach and contributions of the articles to the research questions

2. PUBLISHED ARTICLES AND MANUSCRIPTS

The following sections contain the four articles of this cumulative thesis. Each section will start with an overview of the article, including the conference where results of this paper were presented first time, marking different milestones of this thesis. It will, furthermore, point out the authors' contributions to each article. This introduction is followed by the actual article i.e., manuscript version.

2.1. ARTICLE-I: FARMLAND – AN ELEPHANT IN THE ROOM OF URBAN GREEN INFRASTRUCTURE? LESSONS LEARNED FROM CONNECTIVITY ANALYSIS IN THREE GERMAN CITIES.

2.1.1. OVERVIEW

The article was published in Ecological Indicator and the results of this paper were presented at the IALE 2017 European Landscape Ecology Congress, 12.-15.9.2017, in Ghent, Belgium.

The first author WR developed the methodological framework and research design. All modeling work, data analysis and writing of the manuscript was done by WR. DP supported the data modeling approach methodologically. All co-authors contributed to the manuscript by scientific advice and language editing.

Rolf, W., Peters, D., Lenz, R., Pauleit, S. 2018. Farmland – an Elephant in the Room of Urban Green Infrastructure? Lessons learned from connectivity analysis in three German cities. Ecological Indicators 94(2), 151-163. DOI: 10.1016/j.ecolind.2017.06.055

2.1.2. MANUSCRIPT

Farmland – an Elephant in the Room of Urban Green Infrastructure? Lessons learned from connectivity analysis in three German cities

Werner Rolf, David Peters, Roman Lenz, Stephan Pauleit

Abstract

In recent years, Urban Green Infrastructure (UGI) has gained broad political support and has evolved to become a new research topic in the area of sustainable urban development. The focus has been largely on green urban structures, such as parks and urban forest. The role and contribution of farmland has often been neglected. This work wants to scrutinise the potential of farmland's contribution to the basic conception of UGI, in particular, with regard to connectivity. It reports on three case studies from Southern Germany, in the peri-urban regions of the three largest and expanding cities of Bavaria: Munich, Nuremberg and Augsburg. The spatial analysis we used is transparent, simple and repeatable. It is transferable to any European urban area. We use habitat suitability modelling to map the potential spatial distribution of low-intensity farmland, with emphasis on grassland systems. Based on these potential distributions, landscape indicators are used to analyse structural connectivity. Structural connectivity is used as a surrogate for functional connectivity, which supports ecological and abiotic processes and functions, but on the other hand characterises functional social connectivity, with respect to the accessibility of recreation. The results of this study suggest that farmland bears a great potential to contribute to UGI. The immediate surroundings of the cities do not just offer spatial potential but can enhance connectivity significantly. Based on these results some recommendations have been formulated to enable a better appreciation of farmland and farmers as partners for effectively developing strategies for UGI planning and sustainable urban development.

1. Introduction

1.1. Urban Green Infrastructure

In the past years Green Infrastructure (GI) evolved to a spatial planning strategy for landscape planning in Europe, reaching a broad political consensus. The development of GI belongs to one of the six main targets of the EU Biodiversity Strategy to 2020, to maintain, enhance, and restore ecosystems and their services (European Commission, 2011). To implement the EU Biodiversity Strategy to 2020 the European Commission adopted the GI Strategy, defining GI as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services." (European Commission, 2013). It is being supported by the European Economic and Social Committee (EESC) because of its aim of "linking environmental benefits with economic and social benefits" (EESC, 2013) and by the EU's Committee of the Regions (COR) as well, as it contributes to a sustainable urban model (COR, 2013). Although Urban Green Infrastructure (UGI) has matured in past decades as a spatial planning and design concept for sustainable urban development (e.g., Benedict and McMahon, 2002, 2006; Kambites and Owen, 2006; Walmsley, 2006; Ahern, 2007; Rouse and Bunster-Ossa, 2013; Mell, 2016) this political backup fostered new impulses for European research activities (e.g., Naumann et al., 2011; Davies et al., 2015).

Systematic overviews of different approaches, classification systems, and principles on GI planning are offered by Mell (2016), Young et al. (2014), and Bartesaghi et al. (2016). Although these can be very diverse – reflecting different objectives, contexts and disciplines, in which GI is considered – there is a general consensus that the basic conception in regard to multifunctionality and connectivity are fundamental requirements (Kambites and Owen, 2006; Pauleit et al., 2011). A comprehensive overview of different planning principles, which can take up urban challenges such as biodiversity, climate change adaptation, social cohesion and green economy, is given by Hansen et al. (2016). However, although elements such as public parks, green roofs, street trees, and urban forests are intensively considered and studied as essential components of UGI, it can be concluded that in comparison the role of farmland has been mostly neglected (c.f. Bartesaghi et al., 2016). The omission of farmland is surprising, given that agricultural land dominates many European urban areas (EEA, 2013). Urban and peri- urban farmland thus offers a considerable potential for developing the UGI. For instance in the Ruhr metropolitan region, the largest urban agglomeration in central Europe, nearly 40% is farmland, thus "the most important land user" (Pölling and Born, 2015).

1.2. Urban and peri-urban agriculture

Mougeot (2000) defines urban and peri-urban agriculture (UPA) as "within (intra-urban) or on the fringe (peri-urban) of a town, a city, or metropolis that grows or raises, processes and distributes a diversity of food and non-food products, (re-)uses largely human and material resources, products and services found in and around that urban area, and in turn supplies human and material resources, products and services largely to that urban area". Although, boundaries a rather fuzzy this definition can be related to the understanding of functional urban areas according to (Piorr et al., 2011). Implications of UPA are manifold and have been discussed from various different ecological and socio-economical perspectives (e.g., Allen et al., 2003; Van Veenhuizen and Danso, 2007; Pearson et al., 2010; Zasada, 2011; Mok et al., 2013; Souse and Sales, 2013; Viljoen and Bohn, 2014; De Zeeuw and Drechsel, 2015; Rogus and Dimitri, 2015; Lohrberg et al., 2016).

Philips (2013), Viljoen and Bohn (2014) show how UPA can be considered in urban planning. In the last years too, UPA has been increasingly gained attention from researchers, stressing it in the context of UGI explicitly (e.g., Dunn, 2010; La Greca et al., 2011; La Rosa and Privitera, 2013; Timpe et al., 2015). Dunn (2010) for instance has pointed out positive effects of agricultural use as part of UGI, to stimulate local economy and create green collar jobs, such as organic farming. Furthermore it provides space for food production, lower food costs with benefits for city populations with low income. La Rosa et al. (2014) present a land use suitability strategy model for UGI development in which different forms of UPA play a vital role to enhance urban quality and to improve human health. Timpe et al. (2011) stresses the process of place making, using agriculture to improve life quality and for socio-emotional appropriation of the space. Furthermore there are some practical examples that show, how farmland can be implemented in UGI strategies. For instance the "Green Infrastructure and Biodiversity Plan 2020" of Barcelona, defines the goal "to promote agriculture in the city and outlying areas by applying a model of exploitation that provides social, economic and ecological benefits" (Barcelona City Council, 2013). The agricultural park in Barcelona – Baix Llobregat Agricultural Park – an area of about 3000 ha size, close to the city centre of Barcelona has its own development and management plan taking into account green space provision and landscape recreation (Consorci Parc Agrari Del Baix Llobregat, 2004). Also the City of Milan considers farmers as partners for the development of the green space network within the Regional Ecological Network – Rete Ecologica Regionale (RER) for the Lombardy region (Regione Lombardia, 2010). The "Parco Agricolo Sud Milano" a green belt adjacent to the City of Milan, covering an area of 47.000 ha, is playing and integral role for the development of the network, for protecting and enhancing urban green spaces both, at the city and regional level (Hansen et al., 2016).

Yet, it needs to be considered, that UPA is very diverse, and differs in regard to location, dimension, function, economic activity, motivation, purpose, and actors involved (e.g., Schulz et al., 2013; Mok et al., 2014; Lin et al., 2015; Aerts et al., 2016; Lohrberg et al., 2016). Roughly we can distinguish between small scale gardening activities and large scale, commercial farming activities, although there are many overlaps and hybrids. Farming models that are related to the maintenance of cultural heritage, conservation of agro-diversity and biodiversity, such as explicit environmental friendly production and/or landscape preservation, often linked with the marketing of high value products including the provision of other cultural and social values, are understood "as good examples of agriculture-based green infrastructure within metropolitan areas" (Lohrberg et al., 2016).

1.3. Low-Intensity Farmland and Urban Green Infrastructure

As such low-intensity farmland bears potentials for agriculture-based UGI (Fig. 1). In our means we understand low-intensity farmland as region-specific management practices with variances that is often reflecting prevailing environmental conditions i.e. geophysical factors like soil, climate and topography (cf. Baldock et al., 1993; Beaufoy et al., 1994; Van Velthuizen et al., 2007). This relates to the origins of the concept of "high-nature-value farmland" (HNVf). (Oppermann et al., 2012; Keenleyside et al., 2012). Thus semi-natural pastures, meadows and orchards build an essential part of low-intensity farmland. However, because HNVf is primary understood as an indicator for European Union agricultural and environmental policies and Common Agricultural Policy (CAP) with legal implications (Andersen et al., 2003; Parachini et al., 2006), we rather use the term of low-intensity farmland in our work.

Figure 1. In the designated "Grazing Town Augsburg", a coalition of farmers, nature conservationists and the city administration – the so called Landschaftspflegeverband Stadt Augsburg – promotes grazing management systems, such as traditional transhumance of shepherding, to maintain and develop low-intensity farmland in recreational areas. This serves as a good practice example of low-intensity farmland as part of UGI and its multifunctionality: management of recreation areas with high attractiveness and biodiversity, supporting cultural heritage and agro-diversity in combination with an explicit environmental friendly production of agricultural products (Photo: Liebig, 2009).

In rural areas low-intensity farmland has already been recognised as a useful component in GI strategies (EEA, 2011; Mazza et al., 2011), contributing to core zones (Fritz, 2013) or buffer zones (Benedict and McMahon, 2006). In central European human-dominated traditional cultural landscapes, it is widely accepted that low-input agricultural management practices have sustained biodiversity and ecosystem services over the last centuries

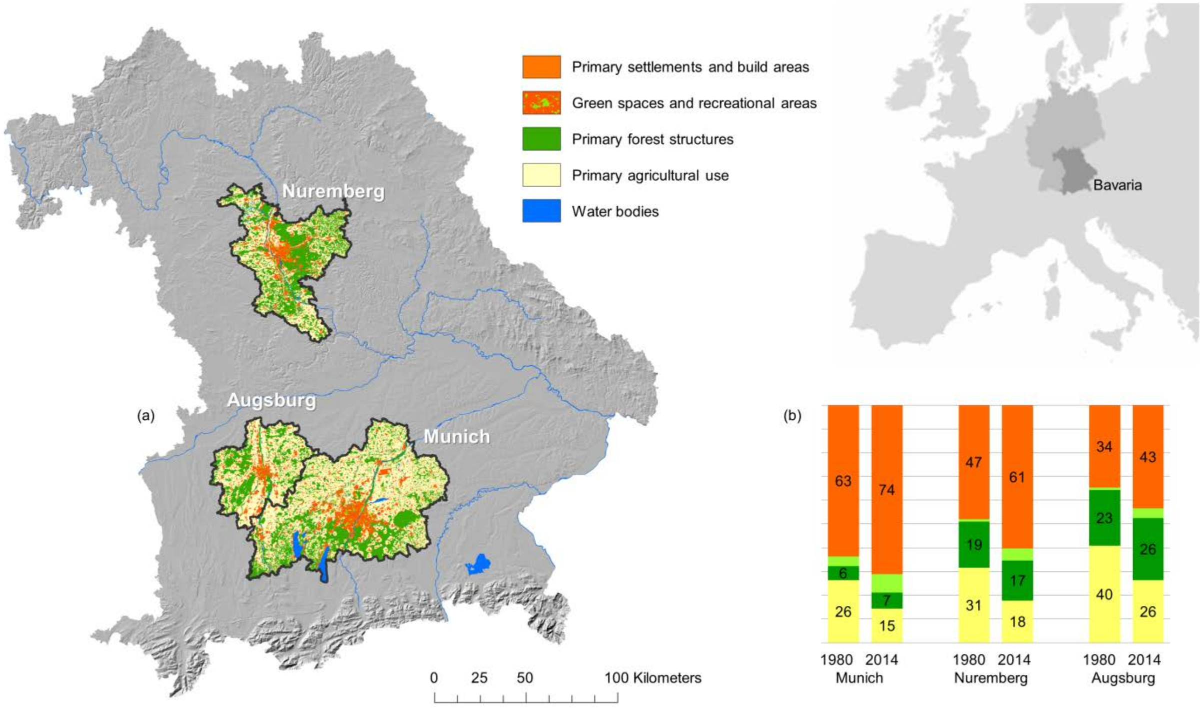

Figure 2. (a) Overview of study area with predominantly land use of the three regions Munich, Nuremberg, and Augsburg (based on European Urban Atlas, 2012); (b) Development of selected land use classes (according to the legend) within the administrative boundaries of the Cities Munich, Nuremberg, and Augsburg from 1980 to 2014 (according Bavarian State Office for Statistics, 2015)

(Jones-Walters, 2008; García-Llorente et al., 2012; Poschlod, 2015). Raudsepp-Hearne et al. (2010) show that low-intensity management can enhance multifunctionality, leading to higher regulating and cultural ecosystem services in peri-urban agricultural landscapes. Furthermore (Hector and Bagchi, 2007; Allan et al., 2015) proved linkages between land-use intensity, biodiversity, and multifunctionality of ecosystem services in several European grassland experiments. Hence, there is empirical evidence, suggesting that at least one of the two basic requirements, namely multifunctionality, can be met by low-intensity farmland, thus improving the quality of the UGI. But what about the second mentioned principle, connectivity? This relates to a second question: how large is the potential in the urban areas, for low-intensity farmland, and where are they?

This study explores the potential contribution of low-intensity farmland with special emphasis on grassland systems, for UGI development, focusing on connectivity. To address this question we use a spatial analysis approach. More specifically, we 1) analyse the potential distribution for low-intensity farmland, in particular grassland systems, and 2) evaluate the spatial distribution patterns in regard to connectivity. This analysis is conducted in the three expanding metropolitan regions Munich, Nuremberg, and Augsburg. The results will not just provide evidence on the potential contribution of low-intensity farmland to the UGI principle of connectivity, but furthermore suggest a transparent and repeatable analytical methodology, transferable to other European urban areas.

2. Data and methods

2.1. *Study area*

The study areas are located in the federal state of Bavaria in southeast of Germany, covering its three largest cities: Munich, Nuremberg, and Augsburg (Fig. 2(a)). Demarcation of our study area is not limited to the cities administrative boundary but contains the surrounding peri-urban region, as defined by the (European Urban Atlas, 2012). All three cities are facing population growth and increased landscape consumption due to settlement and traffic (Fig. 2(b)). Due to urbanisation the share of open spaces within the cities Munich, Nuremberg, and Augsburg reduced in the past primary due to the loss of farmlands. According to the Bavarian State Office for Statistics (2015) the population growth from 1994 till 2014 was around 17% in the City of Munich, 7% in the City of Augsburg, and 4% in the City of Nuremberg. Despite a strong decline of the overall population in Germany until 2034 the expected overall population growth since 1994 will be around 33% in the City of Munich, 14% in the City of Augsburg, and 9% in the City of Nuremberg (Bavarian State Office for Statistics, 2015). Population growth and urban development will increase pressure on urban green spaces. On the other hand it promotes the development of connected green structure for recreation and other social benefits. Already today all three cities show examples of low-intensity farmland contributing to UGI. Thus, the identification of further spatial potentials can be of strong interest in all of these regions.

Munich, the capital of Bavaria, has a population of about 1.5 million inhabitants (Federal Statistical Office, 2014) thus being the third biggest city in Germany and the 12th biggest city of the European Union (Eurostat, 2014); with about 4600 inhabitants per square kilometre it is the city with the highest population density in Germany (Federal Statistical Office, 2014). The Metropolitan Region of Munich belongs to the 10 most important European Metropolitan Regions (BBSR, 2011) the population growth is nowhere else as high in Germany (BBSR, 2012). According to the Bavarian State Office for Statistics (2015) the land use for housing and transport in the city of Munich increased from 63% in 1980–74% in 2014. In the meanwhile the share of green space for recreational use doubled its size and increased from 4% to 8%. While the urban forests increased slightly from 6% to 7% the share of farmland dropped from 26% to 15%. Here, the species rich calcareous grasslands in the Munich gravel plain serve as a local example of low- intensity farmland, maintained by sheep grazing and mowing (Pfadenhauer et al., 2000). Besides their contribution to biodiversity and recreation, these open spaces are considered of high relevance for improving the bioclimatic situation (Munich, 2014).

The second biggest city of Bavaria is Nuremberg. The population of Nuremberg is about 500,000. With more than 2600 inhabitants per square kilometre it has the 7th highest population density in Germany (Federal Statistical Office, 2014). According to the Bavarian State Office for Statistics (2015) the land use for housing and transport in the city of Nuremberg increased from 47% in 1980–61% in 2014. In the meanwhile, the amount of green space for recreational use increased from 1% to 5% while the urban forests decreased from 19% to 17% and the farmland decreased from 31% down to 18%. A local example of low- intensity grassland systems is the nature reserve “Hainberg” at the city fringe. Here the vegetation dynamics of dry acidic grasslands are being maintained by sheep grazing (Quinger and Meyer, 1995). This area belongs to the European Natura 2000 Network (FFH area 6432-301). Besides its importance for biodiversity and recreation, climate analysis show considerably high rates of cold air production within these semi- open landscapes (City of Nuremberg, 2014).

The third urban region considered within this study is Augsburg. The city’s population is about 280,000 with a population density of 1900 inhabitants per square kilometre (Federal Statistical Office, 2014). According to the Bavarian State Office for Statistics (2015) the land use for housing and transport in the city of Augsburg increased from 34%, in 1980, to 43%, in 2014. Meanwhile, the amount of green space for recreational use increased from < 1% up to 4%. Although the urban forests increased slightly from 23% to 26%, the farmland decreased from 40% to 26%. Here again we have a local example of low-intensity farmland contributing to biodiversity, recreation and resource sufficiency (Liebig, 2002; Pantel, 2010). In this case, a coalition of nature conservationists, farmers and the city (the Landschaftspflegeverband Augsburg) has recently initiated the project “Weidestadt Augsburg” in order to promote grazing as a management tool for the maintenance and development of low-intensity farmland (Fig. 1).

2.2. Mapping potential spatial distribution of low-intensity farmland

A few attempts have been made to identify spatial suitability for the development of UPA in the context of UGI (eg. La Greca et al., 2011; La Rosa et al., 2014; Senes et al., 2016). However, none of these considers the land-use intensity of farmland explicitly and the mapping of low- intensity farmland remains challenging (c.f. Wascher et al., 2010; EEA, 2012; Klimek et al., 2014; Lomba et al., 2017). Although various attempts have been made − see Lomba et al. (2015) for an overview – a practical effective suitability mapping methodology remains to be found. We believe that Landscape Character Assessment (LCA) provides this methodology simply by understanding low-intensity farmlands as character areas of region-specific management practices, with distinct and consistent patterns, reflecting biophysical and cultural factors with variances, as outlined above. LCA integrates “natural and cultural landscapes, and people’s perceptions, whilst forming a spatial framework for planning and development” (Van Eetvelde and Antrop, 2009). A comprehensive overview of methods suitable for LCA is given by Wascher (2005), discriminating between methods that are either driven by “simple human (‘expert’) interpretation” or with support of statistical, automated analysis in variants, like “highly automated analysis” or “together with some interpretative refinement”. However, merely human expert-derived approaches seem to be vulnerable to subjectivity, thus not meeting the scientific rigour of repeatability and statistical reliability when taken into account ecological and environmental gradients such as bioclimatic and geomorphological variables (Jongman et al., 2006; Bunce et al., 2008).

Hence, in this work we use Habitat Suitability Models (HSM) as an applicable, transparent, standardised method to effectively identify the spatial potentials of low-intensity farmland. Rolf et al. (2012) have demonstrated the application for traditional low-intensity grassland systems in South Germany successfully (c.f. Lenz and Peters, 2006). Similar approaches have been proven as effective to identify potentials for managed habitat types (e.g., Mücher et al., 2009; Culmsee et al., 2014) and to support nature conservation strategies. For an overview of these modelling principles – other common used terms are ecological niche model or species distribution model (c.f. Ahmed et al., 2015) – we refer to Guisan and Zimmermann (2000), Hirzel and Le Lay (2008), Franklin and Miller (2009), Peterson et al. (2011). Although algorithms are very different the main principles are quite similar, by estimating the distribution of suitable habitat conditions, based on statistical relationships between already known distribution patterns and prevailing environmental conditions. In this case it is important to carefully define the research areas to analyse known occurrences of low-intensity grassland systems. It is also necessary to capture variances of low-intensity farmlands that may potentially occur within the urban region but are no longer present. Therefore we decide not to limit the analysis mask to the urban fringe. Instead the analysis mask for generating the model is set beyond the actual area of interest, analysing known distribution

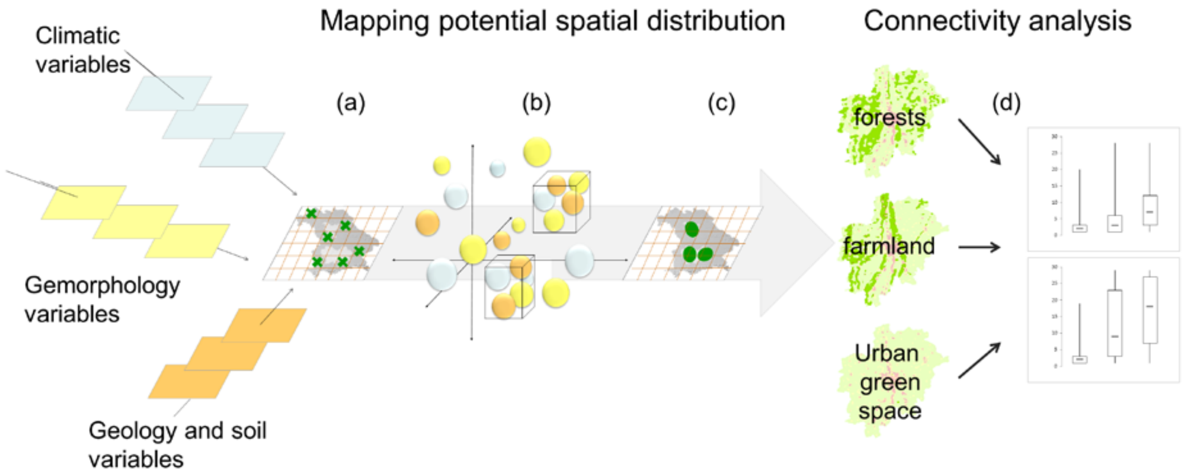

Figure 3. General analysis approach. In a first step known distribution patterns and spatial characteristics (i.e. environmental conditions) are being analysed all across Bavaria (a) to capture all regional variance of farmland (b). Based on these result spatial potentials are identified in a habitat suitability model for the three urban regions (c). Essentially these potentials will be used for comparative analysis of connectivity (d).

patterns across all of Bavaria (Fig. 3a). However, when using the developed model to predict potential areas the mask is limited again to the urban area to project the model (Fig. 3c).

For spatial analysis we applied the maximum entropy algorithm MaxEnt (Phillips et al., 2006; Phillips and Dudík, 2008; Elith et al., 2011) as implemented in OpenModeller (Muñoz et al., 2009). According to Elith et al. (2006) MaxEnt has proven higher predictive accuracy in comparison to other algorithms, in particular if applied to "presence-only" occurrence records.

2.3. *Environmental and landscape variables*

For our case study we use a grid resolution of 100 m × 100 m to handle the data across the federal state of Bavaria. According to Hengl (2006) this can be considered as the best grid size related to an effective map scale of about 1:200,000, thus appropriate for a state wide data analysis, taking into account low-intensity farmland across Bavaria. If at least four pixels are recognised to represent smallest objects, this resolution considers mapping units with a minimum size of about 4 ha. Still this grid resolution provides a comprehensive environmental and landscape database with a coarse resolution for regional planning at the scale of about 1:40,000.

As a consequence of the chosen methodological approach as mentioned above and to take full advantage during data analysis using MaxEnt, all data are primarily prepared as continuous data i.e. gradients rather than categorical data, i.e. patch matrix data model. With this we attain a more realistic representation of landscape heterogeneity while retaining quantitative scales for environmental variables (McGarigal and Cushman, 2005; Cushman et al., 2010; Lausch et al., 2015).

2.3.1. *Preparation of climatic variables*

To characterise climate, we use bioclimatic variables of the Worldclim data base v 1.4 (Hijmans et al., 2005). In a first step we project and interpolate the layers of each Bioclim variable onto the project area. We use non-linear spline interpolation in ArcGIS setting tension to 0 Φ (phi). Ultimately these settings represent a basic thin plate Spline interpolation (Franke, 1982) to remove artefacts, minimize overall surface curvature, resulting in smooth surfaces. Thin plate Spline interpolation is particular suitable for processing climate data, as it has been originally developed for this purpose (Wahba and Wendelberger, 1980; Franke, 1982) and was also applied by initially creating the climate surfaces of the Worldclim data set.

Because some climatic variables are highly correlating in a second step we reduced redundancies using Principal Component Analysis (PCA). Essentially the 19 variables were reduced into 3 data layers, characterising the climatic space (Fig. 4).

Figure 4. Result of PCA to model climate space of Bavaria, based on Bioclim variables: the different colours reflect differences of climate condition.

Table 1. Brief description of the used indices, data sources, and used tools to derive geomorphology variables for habitat suitability model.

Variables	Description	Source of original data1 and used tools of derived data2
Elevation index (1)	Height in Meter, based on DEM (resolution of 50 m)	Original data (Geodaten Bayern, 2015)
Roughness index (2)	Characterising topographic heterogeneity (Riley et al., 1999) by calculating variances of elevation within an analysis window of 100 m	Geomorphometry and Gradient Metrics Toolbox (Evans et al., 2014)
Landform index (2)	Characterising surface curvature (McNab, 1993), defined by relative concavity and convexity, based on different variants using three different analysis windows (500 m, 2,000 m, 10,000 m)	Geomorphometry and Gradient Metrics Toolbox (Evans et al., 2014)
Slope index (2)	Characterising slope steepness in degree, based on the mean of slope within the analysis windows of adjacent cells.	ArcGIS 10.3 - Toolbox Slope (ESRI, 2014a)
Site exposure index (2)	Characterising slope aspect and steepness combined, representing relative exposure (Balice et al., 2000)	Geomorphometry and Gradient Metrics Toolbox (Evans et al., 2014)
Heat load index (2)	Characterising solar radiation across landscape (Fu and Rich, 2003), accumulating global insolation from March 15th – September 15th	ArcGIS 10.3 - Toolbox Solar Radiation (ESRI, 2014b)
Moisture index (2)	Estimating soil moisture, based on flow in the landscape, based on topography using based on flow accumulation (Jenson and Domingue, 1988)	ArcGIS 10.3 - Toolbox Hydrology / Flow Accumulation (ESRI, 2014c)

The superscript numbers are according to original data (1) and derived data (2)

2.3.2. *Preparation of geology and soil variables*

In the next step we characterise prevailing site conditions related to geology and soil. Geological maps and soil maps are often represented by categorical data or is in large scape either incomplete or inhomogeneous. In the federal state of Bavaria for instance, the geodata base is just covering few parts of the soil overview map in the scale of 1:25,000 (ÜBK25) within the peri-urban regions of this study. The newly published German Soil Atlas (Kruse and Schubert, 2016) is very partially based on data in the scale of about 1:1 Mio. (BUEK1000), such as the field capacity in the effective root zone. To integrate data representing landscape heterogeneity we use the topsoil physical properties, based on LUCAS topsoil survey information (Panagos et al., 2012; Ballabio et al., 2016). Although this information is still rather coarse, it provides a first approximation of the prevailing conditions related to soil stability, water retention characteristics, and agricultural productivity (Fig. 5). Besides using this data base simplifies to transfer the method on other regions because of data availability. The data are originally available in the resolution of 500 m × 500 m and have been resampled using ArcGIS cubic resampling technique, leading to smooth data curve based on the surrounding 16 data cells. Further refinement of local site characteristics depending on differentiated pedogenesis is being achieved with additional geomorphology variables (see next section).

2.3.3. *Preparation of geomorphology variables*

Although several climatic and soil variables are integrated in the model so far they still do not reflect local variations based on topography. For further refinement several geomorphology variables are derived from the digital elevation model (DEM), characterising land surface parameters (Pike et al., 2008). These variables further differentiate physical and biophysical processes influencing local climate or pedogenesis, affecting site productivity and distribution of land use (Table 1). The parameters are derived using "Geomorphometry and Gradient Metrics Toolbox" (Evans et al., 2014) and ArcGIS. To ensure the highest accuracy, these indices are calculated using the DEM with best resolution available – 50 m × 50 m (Geodaten Bayern, 2015).

2.4. *Incorporating low-intensity farmland*

Low-intensity farmland systems can be very different across Bavaria, with site conditions ranging from wet to dry, alkaline to

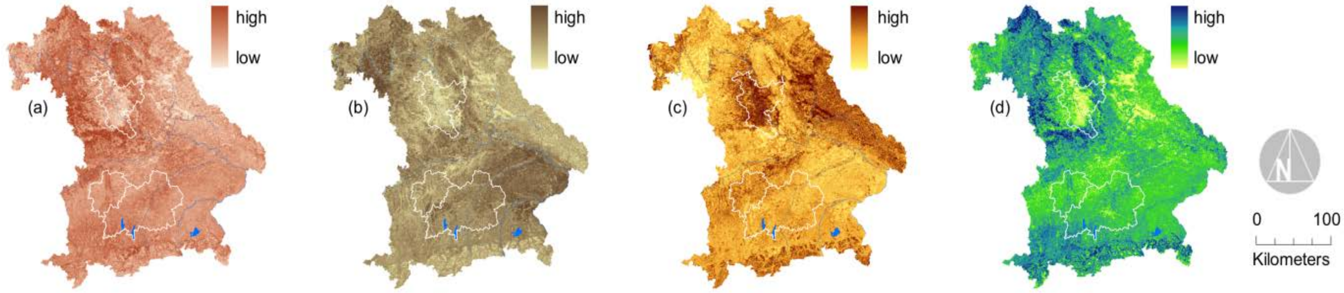

Figure 5. Physical soil properties (based on Ballabio et al., 2016): clay content in topsoil (a), silt content in topsoil (b), sand content in topsoil (c), and available water capacity for the topsoil fine earth fraction (d).

Table 2. Brief description of variances of low-intensity farmland (i.e. grasslands systems) and related habitat type according to Bavarian biotope mapping system [1] and Fauna-Flora-Habitat type [2].

Low-intensity farmland system (grassland)	Description	Related habitat types
Low-intensity grazing or mowing in lowlands	Mowing or grazing in lowlands. Sites can be humid to wet or even semi dry. No or only little fertilization. Mowing is often not taken prior to the main flowering period of the grasses, often rotational grazing system.	Species-rich low-intensity grassland (GE)[1]; Lowland hay meadows (LRT 6510)[2]
Low-intensity grazing or mowing at calcareous sites	Dry and semi-dry calcareous grasslands, formed by low-intensity grazing or mowing.	Calcareous grasslands (GT)[1]; Semi-natural dry grasslands and scrubland facies on calcareous substrates (6210)[2]; Juniperus communis formations on heaths or calcareous grasslands (5130)[2]
Low-intensity grazing or mowing at acidophilous sites	Dry and humid variances of grasslands at shallow, acid soil or sands. Usually formed by low-intensity grazing or mowing without or very little fertilizing in low mountain ranges.	Acidophilous grasslands (GM)[1]; species-rich Nardus grasslands, on silicious substrates (6230)[2]

acid, from lowland to alpine (c.f. Oppermann, 2012). Often they can be accounted to species-rich grasslands with a high nature value but can also be found as grasslands with impoverished flora and fauna, for instance due to land use intensification. To capture the broad spectrum with our habitat suitability model, we derived data from the habitat monitoring program of the state of Bavaria (BayLFU, 2010). First records of this monitoring have been made in between 1974 and 1977, at the scale of about 1:50,000. The first mapping in a detailed scale of 1:5.000 has been finished between 1985 and 1995. Since 2006 the habitat types have been adapted according the European Habitats Directive 92/43/ EEC (Fauna-Flora-Habitat). A second round has been completed partially (BayLfU, 2015a). Although incomplete this builds a sufficient data base, to select and calibrate a broad spectrum of biophysically relevant environmental variables, that can be assigned to semi-natural grassland systems for low- intensity farmlands (Table 2). The relevant habitat types have been selected and extracted from the geodatabase − provided as Shape-File and MS Access database (BayLfU, 2015b).

2.5. *Comparative analysis of connectivity − with and without low-intensity farmland*

Connectivity, inherent in the UGI concept, aims at the development of a network, to support and enhance processes, functions and benefits that are limited without these interlinkages (c.f. Ahern, 2007; Hansen et al., 2016). Connectivity can be very diverse and differentiated between structural and functional connectivity (Merriam, 1984; Baudry and Merriam, 1988). Studies of connectivity planning for urban green space often focus on the ecological context, facilitating movement and interactions for wildlife (e.g., Rudd et al., 2002; Parker et al., 2008; Kong et al., 2010; Oh et al., 2011). However, one essential of UGI networks is to enhance social connectivity for humans (Hansen et al., 2016), for instance to support sustainable mobility or to enhance accessibility for recreation i.e. distance to residential areas (e.g., Little, 1990; Bischoff, 1995; Kent and Elliott, 1995; Shafer et al., 2000; Bryant, 2006; Koppen et al., 2014). Abiotic connectivity can influence flows of energy (e.g., Soulé et al., 2004; Brauman et al., 2007; Bagstad et al., 2014), like water dynamics with benefits for stormwater management, or air ventilation leading to improved air quality or cooling effects in urban heat islands. The requirement to consider connectivity object- related has been outlined by Taylor et al. (2006) and different approaches have been developed in the last few decades (e.g., Keitt et al., 1997; Tischendorf and Fahrig 2000; Calabrese and Fagan, 2004; Bélisle, 2005; Fischer and Lindenmayer, 2007; Rayfield et al., 2011). For an in depth discussion of different connectivity indices see Gustafson (1998), Goodwin (2003), and Kindlmann and Burel (2008).

However, a comprehensive analysis of connectivity, considering all the functional aspects separately, goes beyond the scope of this work. Rather, we use structural connectivity as a surrogate for the functional elements of connectivity, assuming that low-intensity farmland contributes to effective ecological networks (c.f. Beaufoy et al., 2012) and contributes to positive effects on the thermal climate of surrounding beneficial for human health and biophysical processes, even more if low-intensity grassland structures contain scattered trees (c.f. Bowler et al., 2010; Norton et al., 2015; Di Leo et al., 2016; Lee et al., 2016). Following Koppen et al. (2014) and Poelman (2016) our approximation relates to the accessibility of recreation, within distance of about 10 min walking time, based on neighbourhood analysis. Hence, this approach can – in some regards – enable comparison with functional connectivity explicitly. Technically, our results are based on neighbourhood distance analysis, using focal statistics calculations in ArcGIS, with an analysis radius of about 300 m radius.

Comparative analysis is done for each urban region (Fig. 3d). First we calculate the grade of accessibility based on the land use classes “green urban spaces”, “water”, and “forests”, as determined by the (European Urban Atlas, 2012). Secondly we include low-intensity farmland in the calculation as mapped in section 2.2. Thus we can directly compare the grade of connectivity in UGI both without farmland and considering farmland. Because we expect within the peri-urban region of Munich, Nuremberg and Augsburg, areas that might be pre- dominantly characterised as rural with a large share of farmland, we need a second comparison. Therefore the area of comparison will be limited to the administrative city border, to determine the impact of low-intensity farmland in the centre of each of the three metropolitan regions.

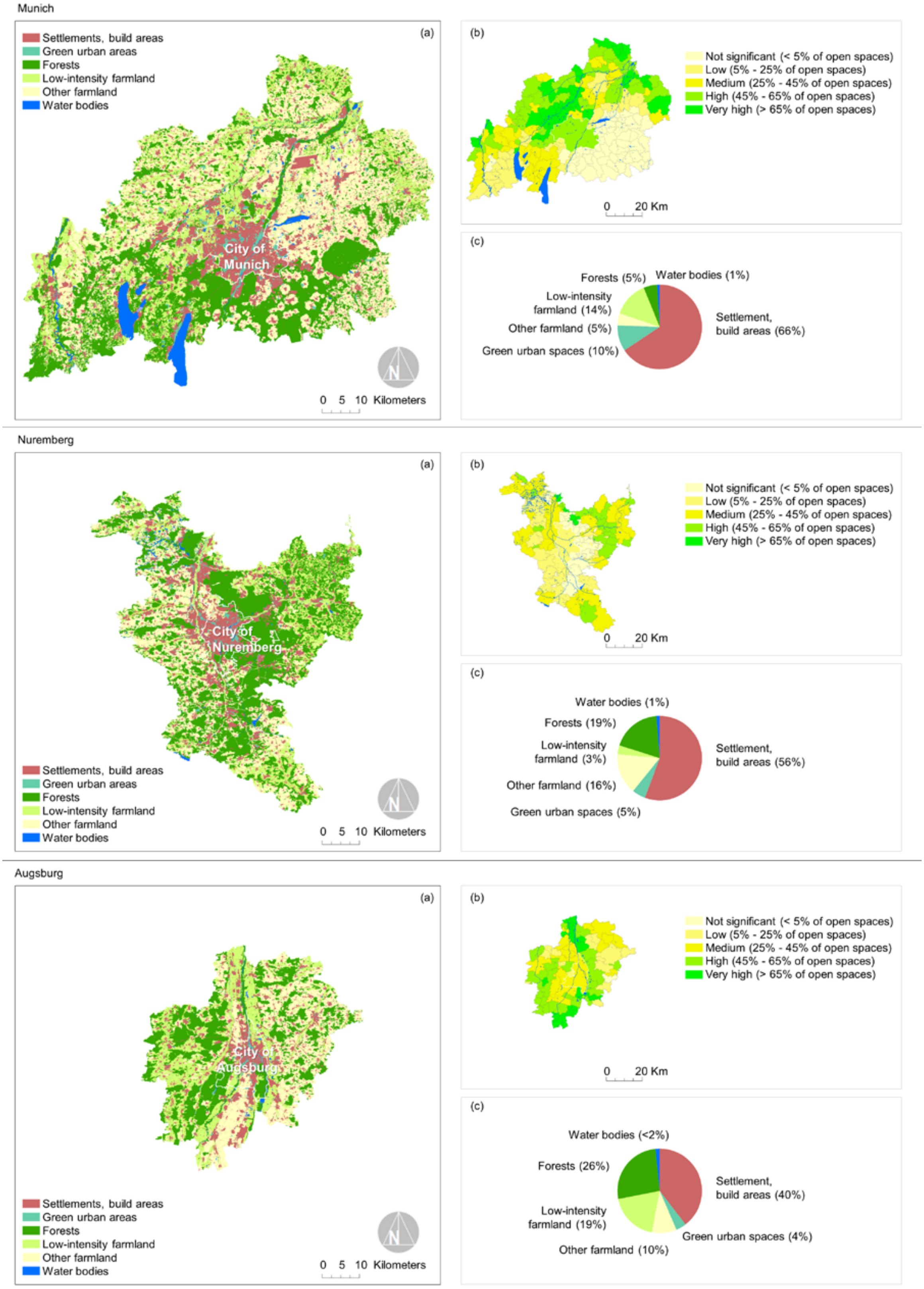

Figure 6. Mapping results of low-intensity farmland potentials in each region (a); spatial distribution of mapped low-intensity farmland potentials at municipality level (b); share of land uses in each city (c)

3. Results

3.1. *Mapped potential areas of low-intensity farmland*

Fig. 6a illustrate the results of the mapped potential areas for low- intensity farmland in each region and its spatial distribution. The total land share of farmland is about 41% in the region of Nuremberg, 53% in the region of Munich, and about 56% in the region of Augsburg. The share of estimated low-intensity farmland ranges from 17% in the region of Nuremberg (41% of the regions farmland), and 19% in the region of Munich (35% of the regions farmland), up to 25% in the region of Augsburg (45% of the regions farmland). In comparison forest covers about 29% in the region of Munich, 31% in the region of Augsburg and 42% in the region of Nuremberg. Thus, in Munich and Augsburg farmland is the most important land use with a big share of potentially low-intensity farmland; in Nuremberg the farmlands total area is about equal to the total sum of forests.

Having a closer look into the regions, comparing at the administrative level of municipalities, the mapped potential areas show that the results differs widely (Fig. 6b), showing spatial variations. Here the share of mapped potential areas for low-intensity land-use is ranging from not significant up to highly significant, with the highest share of almost 80% in a village north of the city of Augsburg, where almost 100% of the farmland within the municipality is estimated as potential low-intensity farmland. In the region of Munich the highest estimated share is about 71%, in a village at the region's western edge, covering about 95% of the total farmland in this municipality. The highest estimated share in the region of Nuremberg is about 52%, a village in the north-eastern part of the region (which is about 90% of the municipality's farmland).

Fig. 6c illustrate the comparison of the share of land use within the cities. According the geodata the total farmland covers about 28% in the City of Augsburg, about 19% in the City of Nuremberg, and 18% in the City of Munich.

The share of the mapped potentials of low-intensity farmland is lowest in the City of Nuremberg with about 3% (18% of the total farmland within the city), followed by almost 14% in the City of Munich (75% of the total farmland within the city), and finally 19% in the City of Augsburg (about two thirds of the total farmland within the city). In comparison forest and other urban green spaces cover about 15% in the City of Munich, 30% in the City of Augsburg and again 30% in the City of Nuremberg. Besides the results outline a small but considerable share of open water, which is about 1% of the areal surface in all three cities. These are mainly the Lech and Wertach River in Augsburg, the Isar River in Munich and the Pegnitz River in Nuremberg, as well as several little lakes in all three cities. Although the share is comparatively small, these structures, including their green space sideways of the rivers and canals, need to be noted, as they can have a high significance for the connectivity of both: biodiversity and recreation, and are furthermore relevant for regulating factors, for instance for air ventilation.

3.2. *Comparative analysis of connectivity – with and without low-intensity farmland*

Table 3 summarises connectivity – i.e. the amount of the mapped potential of low-intensity farmland in comparison to green urban spaces, forests and water within walking distance of about 10 min walking time. Analysis results show that in all three regions the contribution of low-intensity farmland is significant, even higher than of forests and of green urban structures (such as parks) and water bodies (such as rivers and lakes), thus contributing to overall connectivity if all different classes are considered together. Switching scale and looking at the three cities solely the situation is different. Here the contribution of green urban structures is highest. Nevertheless, the contribution of low- intensity farmland to connectivity is more significant than forest structures in two of three cases. With about 15% the contribution in the City of Munich is twice as high than the contribution of forest in the City of Augsburg even three times higher. Merely in Nuremberg forest is more significant and more than twice as high as of low-intensity farmland.

Table 3 Mapping results summarising contribution of different types of green spaces to connectivity, i.e. accessibility within 10 min walking time.

	Share of settlement that has access to each of the different green space classes			share of settlement within that has access to the sum of different considered classes	
	green space a)	forests b)	farmland c)	green space + forest d)	green space + forest + farmland e)
City 1) of:					
Augsburg	44 %	8 %	24 %	50 %	64 %
Munich	50 %	7 %	15 %	55 %	62 %
Nuremberg	47 %	23 %	11 %	62 %	67 %
Region 2) of:					
Augsburg	27 %	23 %	51 %	46 %	74 %
Munich	37 %	26 %	38 %	55 %	72 %
Nuremberg	33 %	42 %	43 %	66 %	80 %

a) contains the classes "green urban spaces" and "water", as determined by the European Urban Atlas (2012); b) contains the class "forests" as determined by the European Urban Atlas (2012); c) contains the mapped spatial potential of low-intensity farmland; d) contains the classes "green urban spaces", "water", and "forests", as determined by the European Urban Atlas; e) contains the classes "green urban spaces", "water", and "forests", as determined by the European Urban Atlas, and the mapped spatial potential of low-intensity farmland; 1) City relates to the municipality level (political city boundaries); 2) Region relates to total region according to the European Urban Atlas (2012).

Fig. 7 illustrates the difference in its spatial distribution within the three cities. Distribution patterns show that green urban spaces is often embedded in the settlement structure, thus being accessible within distance by people living in the surrounding housing areas. Opposed to this forests and farmlands are in all three cities primary along the edge of the cities, as part of the adjacent open landscape. Hence, accessibility is less, for fewer housing areas.

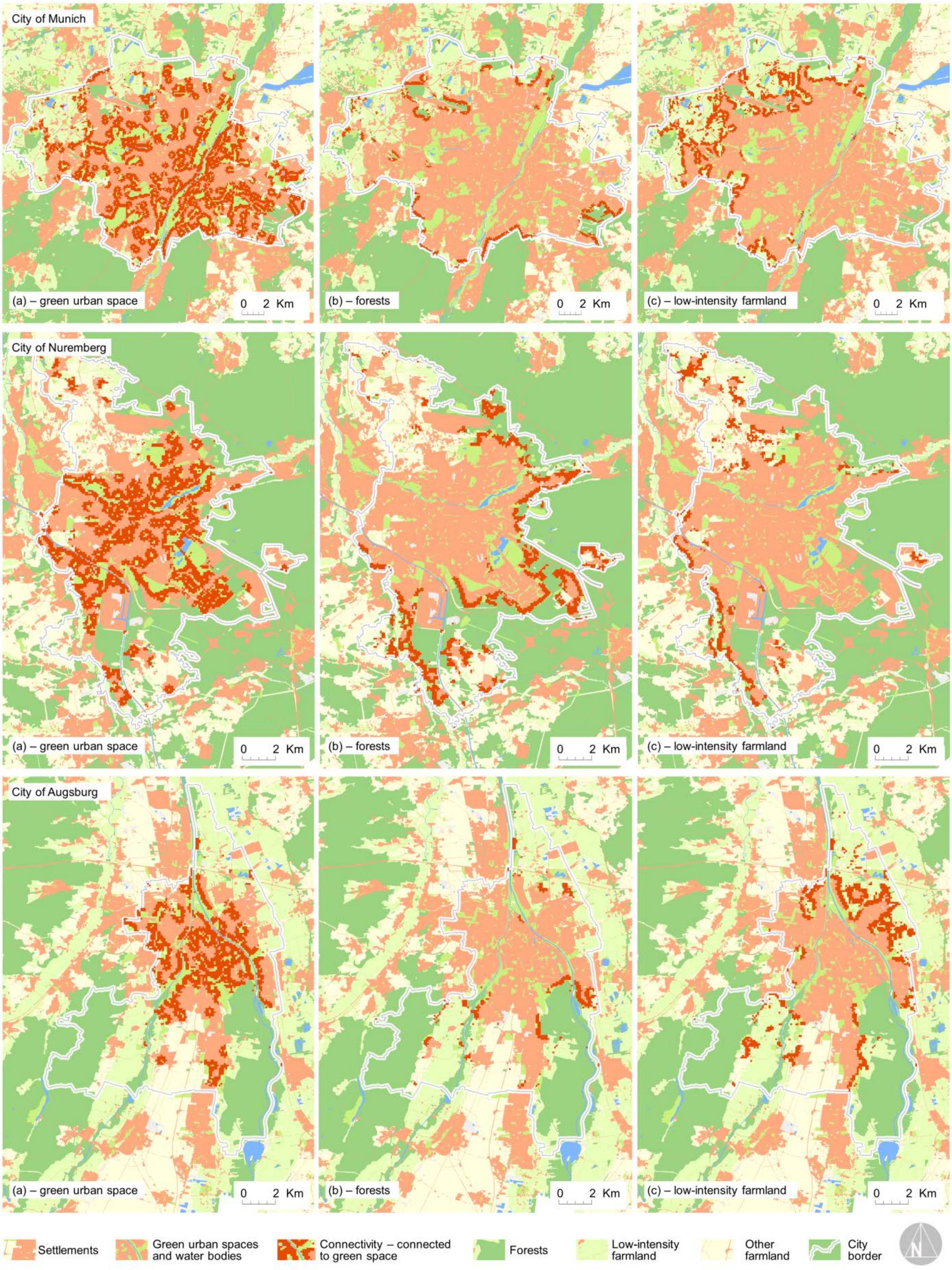

Figure 7. Spatial patterns of connectivity areas in each city, depending on structure – green urban spaces including rivers and lakes (a), forests (b), and the mapped potentials of low-intensity grassland (c).

4. Discussion and conclusion

The results of our study provide new insights into the spatial significance of farmland and in particular low-intensity farmland as part of UGI and in regard to the connectivity principle. Furthermore, we present an analytical methodology that is transparent, repeatable and transferable to other European urban areas and suitable to be adapted for UGI planning. Thus, this approach supports a more differentiated consideration of farmland and its potentials for UGI planning.

For final discussion and conclusion we want to focus at three aspects: mapping of low-intensity farmland potentials, connectivity analysis, and finally, implications for UGI planning.

Since the mapping of low-intensity farmland is still challenging, the proposed approach can be a simple workaround, to identify current distribution and spatial potential for low-intensity farmland. However, for assessment and consideration in planning we suggest refining the results of this mapping approach, by combining them with other geodata available, such as the estimation of HNVf based on CORINE Land Cover 2006 (Paracchini et al., 2008) and if possible other national habitat monitoring programmes, containing current distribution of low- intensity farmlands. Furthermore, we can note that during this work the first time a map of the bioclimatic space for Bavaria has been developed, based on multi-variate analysis of Bioclim data. We want to encourage further use of this approach in other contexts, in order to enrich data base for enhanced GI planning. Furthermore we would like to encourage the use of the proposed modelling approach for urban green space planning in particular for integrating conservation planning. It can be useful to effectively identify spatial potentials to protect biodiversity, based on potential habitats and species distribution, in particular if appropriate information is incomplete and exhaustive field mapping unfeasible (c.f. Milanovich et al., 2012; Sushinsky et al., 2013; Lerman et al., 2014). The main challenge here is the consideration of biophysical and anthropogenic variables for the model that meet habitat preferences appropriately.

Regarding connectivity analysis we have to admit – and we are fully aware –, that the analysis performed here has limitations:

Although this approach considers functional connectivity in regard to accessibility of green space, this analysis can still be enhanced using network analysis tools to measure distance through existing infrastructure, leading to more precise results − see Pafi et al. (2016) for an example. Furthermore it is also crucial to understand that accessibility does not mean access by walking directly across low-intensity farmlands, in particular as entering grasslands and pastures may be prohibited by nature protection law or prevented by fences. However, the access rather occurs while walking at adjacent paths or trails that lead along these farmlands.

Besides we need to be aware that connectivity is object-related and the result of complex interactions (Merriam, 1984; Taylor et al., 1993; Tischendorf and Fahrig, 2000; Calabrese and Fagan, 2004; Taylor et al., 2006). Thus, this analysis approach can still be refined by more adequate and specialised metrics and further indicators that meet these requirements – regarding ecological, social and abiotic connectivity. Because connectivity is in particular crucial if service providing areas and service benefiting areas are spatially separated (Syrbe and Walz, 2012; Mitchell et al., 2013), we furthermore need to better understand and consider these spatial segregations and interactions for UGI planning. Concluding this, although this approach allows a first approximate to connectivity further work is needed and we hope to answer some of these questions in future work.

Finally we want to discuss the results and draw conclusion for UGI planning:

The outcome of our analysis is clear, stressing the spatial potential of low-intensity farmland for UGI development. As expected, farmland builds a significant share in all three regions, in some parts representing the most important land user with a big share of potential for low- intensity farming, although these vary within the regions. Consequently low-intensity farmland contributes to connectivity for UGI. However, more surprisingly is the outcome that, looking at the level of city area, low-intensity farmland potentials appear to contribute even more to connectivity than forest does. Still, green urban structures (such as parks) and water bodies (such as rivers and lakes) contribute most to connectivity, within the built settlement structure. This seems to be due to the shape, pattern and structure of land use. Whereas small green urban spaces can effectively contribute to a high connectivity within city, because of its accessibility for surrounding housing areas, neither large low-intensity farmland nor large forests necessarily achieve similar connectivity benefits. In other words, the ratio of area-size and its contribution to connectivity at the city's fringe can be considered as lower, as these areas are less accessible to housing areas, although in size much larger.

However, this does not reveal the complete picture of how low-intensity farmland contributes to UGI in regard to connectivity. As we mentioned in the methods section UGI planning must also consider connectivity in the context of service provision areas and service benefiting areas and the benefits to these linkages that come with low- intensity farmland. Our study focused on social connectivity, neglecting ecological or abiotic connectivity. Nevertheless, even this needs further reflection about how urban citizens really appreciate and valorise the recreational experience in low-intensity farmlands, for instance in comparison to urban parks and urban forests, and not least intensively managed farmland. Currently the benefits are rather hypothetical, assuming that low-intensity farmland is principally being appreciated by people as they offer cultural values. We want to gather more evidence on this question in our future work.

The authors hope that this work will ignite interest in the topic of farmland and its functions in the context of integrated UGI planning, and further, that it provides insights into how farmland is a major and an effective contributor to UGI.

Finally, we would like to emphasize the importance of farmers as partners in both the planning and development of UGI and a sustainable urban future.

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2.2. ARTICLE-II: ALGORITHMIC LANDSCAPES MEET GEODESIGN FOR EFFECTIVE GREEN INFRASTUCTURE PLANNING – IDEAS AND PERSPECTIVES

2.2.1. OVERVIEW

The article was published in the Journal of Digital Landscape Architecture (JoDLA) and the results of this paper were presented at the 21st International DLA Conference 2020 (virtual), 3.-5.6.2020, at Harvard University, Boston, US.

The article was developed by the two authors, led by WR. The original idea came from WR and has been further developed together with the co-author. Each authors contributed an application study. The writing was done by WR with editorial support from DP.

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2.2.2. MANUSCRIPT

Algorithmic Landscapes meet Geodesign for effective Green Infrastucture Planning. Ideas and Perspectives.

Werner Rolf, David Peters

Abstract

In this paper we discuss the potential of incorporating algorithmic landscapes in Geodesign to enhance Green Infrastructure (GI) planning. In the first part of this paper we identify the matches between all three subjects and how the methods may benefit from each other. GI planning is an ecological framework for environmental, social and economic sustainability. It aims to develop an interconnected network of green spaces that provide ecosystem functions and benefits for multiple values. As an interdisciplinary approach involving a variety of stakeholders the challenge is to enable all to understand complex ecological processes and interactions on a landscape scale. Geodesign offers design strategies and procedural techniques for communication and understanding of the geographic context and emphasizes collaboration and co-design. Biophysical algorithmic landscapes can present intuitively appealing visualizations of complex data that can enable all stakeholders to appreciate both the landscape and the underlying environmental and ecological patterns in their area of interest. Both GI planning and Geodesign attempt to formalise a very complicated process and the incorporation of more algorithmically based inputs would seem to fit well with this endeavour. In the second half of the paper we present two examples of applications that have used algorithms for green planning. The first one uses habitat suitability modeling to identify spatial potentials for ecosystem functions and services. The second one uses assemblage modeling to integrate bio-physical data and generate an "all in one" map for use in regional nature conservation planning in Australia. Although neither presents a 'ready-to-use'-solution they illustrate the potential of suitable algorithms for more formal integration in Geodesign processes. Geodesign in turn can support the communication strategy within GI planning through its emphasis on stakeholder involvement. Thus, the algorithmic approach together with Geodesign show abilities to raise understanding and appreciation for ecological processes, functions and associated human benefits among the different stakeholders to support GI planning processes.

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1. *Setting the scene: How to get the horse before the cart*

1.1. *What is Green Infrastructure Planning?*

Although the term 'Green Infrastructure' (GI) is relatively new, its ideas are related to earlier concepts of urban planning (Wright 2011) and conservation of biodiversity, such as habitat and wildlife networks and ecological corridors (Ahern 2007). The concept of GI emerged in the United Stated in the late 1990's in response to urban sprawl with its negative effects on landscape and nature (Rouse and Bunster-Ossa 2013). The intention was to integrate green "infrastructure' into spatial development as an "interconnected network of green spaces that conserves natural ecosystem values and functions and provides associated benefits to human populations" that could provide "the ecological framework needed for environmental, social and economic sustainability" (Benedict and McMahon 2002). In the meanwhile, it evolved very dynamically on different scales, putting emphasis on various objectives addressed by a number of disciplines, such as ecology and conservation biology, regional and urban planning, landscape architecture, water resource management and transportation (Kambites and Owen 2006, Tzoulas et al. 2007, Mell 2010, Sinnett et al. 2015). Unchanged is the common understanding that GI "aims to create multifunctional networks of green spaces" with connectivity and multifunctionality as two inherent key principles (Pauleit et al. 2017). It is understood as an integrated cross-sectoral spatial planning approach, comprising biodiversity planning, along with a number of different landscape functions and services such as water, climate, fluxes regulation as well as taking into account social and cultural benefits. As a prerequisite, the understanding of natural resources and the environment and their capacities to support ecosystems and their services are essentials for sound GI planning. Hence, successful GI planning needs communication strategies to raise understanding and appreciation of ecological processes, functions and associated human benefits among all the different stakeholders.

1.2. *What is Geodesign and why is it good for Green Infrastructure Planning?*

According to Miller (2012) the basic concept of Geodesign can be understood as design that relates to geographical context, i.e. the natural conditions of a site and its surroundings. This approach was used by earlier influential architects and landscape architects including Frank Lloyd Wright (1867-1959), Richard Neutra (1892–1970), Warren H. Manning (1860- 1938) and Ian McHarg (1920-2001). The term "Geodesign" was introduced by Steinitz (2012)

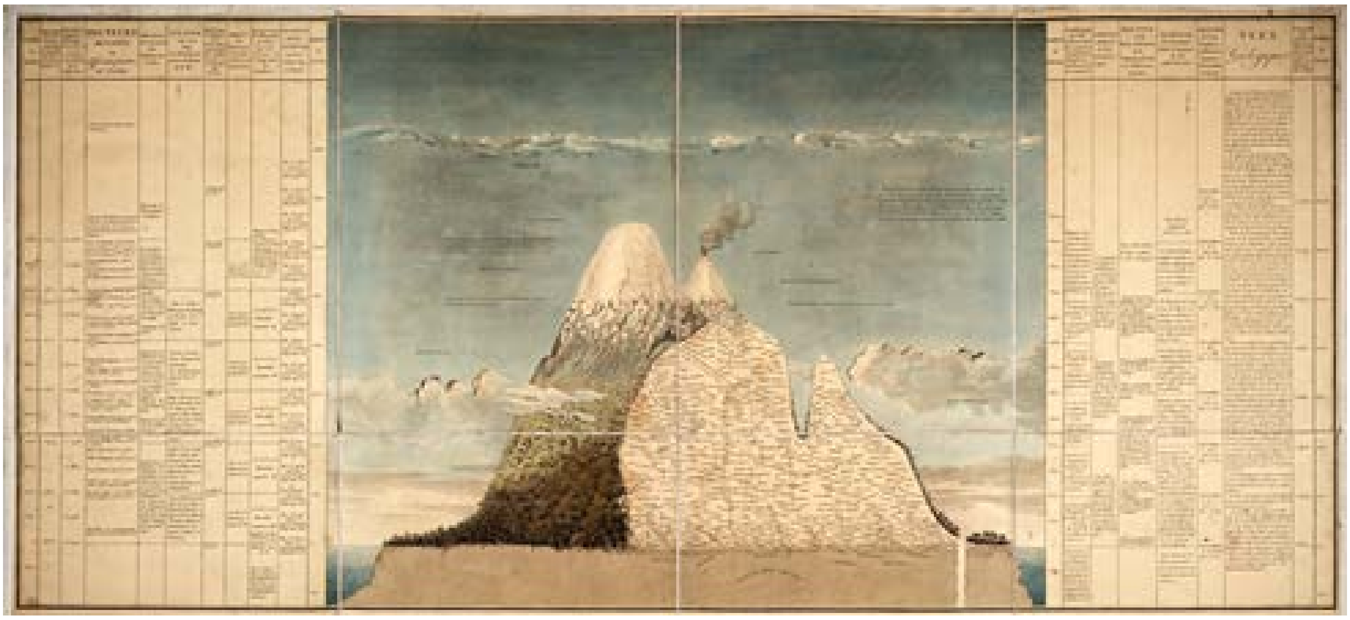

Figure 1. Painting of the Chimborazo volcano is a formalised representation und inter-pretation of environmental phenomena by Alexander von Humboldt and Aimé Bonpland - possibly the first algorithmic landscape ever modeled (Source: Peter H. Raven Library/Missouri Botanical Garden, http://botanicus.org/page/1061689)

to brand his conceptual framework that consists of design strategies and procedural techniques that essentially benefit from the integration of both Geographic Information Science (Goodchild et al. 1991, Longley et al. 2011) and creative design. Because Geodesign is considered as an interdisciplinary approach involving different stakeholders in the design process it aims to provide methods and tools that promote collaboration and co-design.

As mentioned above, for successful green infrastructure planning, interdisciplinary approaches are needed that enable different professions and actors from government and the community to work together (Pauleit et al. 2020). Hence, GI planning would likely benefit from Geodesign for the communication and understanding of the geographic contexts through Geodesign's promotion of collaboration in the spatial planning processes.

1.3. *What are Algorithmic Landscapes and why are the good for Green Infrastructure Planning?*

The origin of the term 'algorithmic landscape' may be found in the field of digital art and computer simulation, particularly for the creation of artificial worlds in videogames and movies (Langston 2012, Dolan 2018). Basically, 'algorithmic landscapes' can be understood as landscape representations that have been digitally processed and manipulated, ideally reflecting spatial patterns of underlying landscape variables and processes in the most realistic manner (c.f. Cureton 2016). We may thus consider Alexander Humboldt's 'Tableau physique des Andes et pays voisins' as an earlier 'analogue' historical precursors of an algorithmic landscape (figure 1) (c.f. Claghorn 2018). The painting synthesises spatial patterns and interactions of a number of environmental variables, such as elevation, soil, climate, vegetation, based on data from several years of field observations and measures during the years 1799-1803.

Recently designers in landscape architecture started experimenting with algorithms to support design concepts (Claghorn 2018). One of the more established applications in landscape architecture is the one of 'digital botany' used for high-end visualization of vegetation structures (Prusinkiewicz and Lindenmayer 1990, Rekittke and Paar 2006). At the same time, various landscape oriented disciplines have developed suitable algorithms to analyse and model patterns of spatial arrangements, topological relationships and networks, spatial growth, flow of energy, matter, and information as well as spatial interactions, behaviour, and response. Digital geographic information offers opportunities to analyse of complex systems and spatial implications of dynamic processes. As such potential applications of algorithmic landscapes can be very broad and manifold.

In this paper we focus on representations of the biophysical landscape that are generated by algorithms applied to real world data. Algorithmic-based methods have been developed in the past decades adding new perspectives to traditional expert-based, qualitative methods, integrating existing environmental models into geographical information systems (Kemp 1997). In the meanwhile algorithms have undergone a number of advancements to delineate and visualize landscapes (e.g. Belbin 1995, Hargrove and HoffmaN 2005, Kreft and Jetz 2010). The application of biophysical 'algorithmic landscapes' provides insights into interrelationships between the biological and physical systems of the landscape, directly supporting ecological oriented planning and design (c.f. Mcharg 1969, Murphy 2016). Thus, they can help all stakeholders to appreciate the landscape and its underlying environmental and ecological patterns in their area of interest, supporting GI planning.

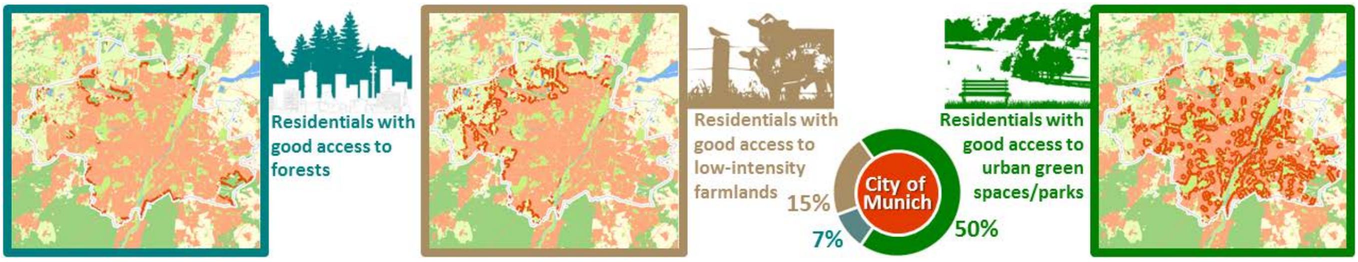

Figure 2. Example of habitat suitability analysis used to identify potentials for low-intensity farmland (grassland systems) as multifunctional open green space for urban dwellers, in the City of Munich, Germany (adapted from Rolf et al. 2018)

1.4. How do Algorithmic Landscapes fit with Geodesign?

The Geodesign framework can be broadly divided in two phases: the descriptive/evaluative (representation/process/evaluation) and the prescriptive/planning (change/impact/decision) part (Steinitz 2012). The two phases are strongly related to the dynamic interrelation of spatial patterns and ecological processes of the landscape and secondly, to how landscape planning, in turn, alters landscape patterns, processes and functions. As mentioned earlier, potential applications of algorithmic landscapes to support design processes may be manifold (Claghorn 2018). Potentially they can show how ecological processes interact across spatial patterns which is exactly what Geodesign needs for its change models.

"Representation models" are Geodesign's views of the inputs to its planning process and algorithmic landscapes are perfectly suited to delivering these. They can be used to communicate the reference geographic context, intuitively accessible to all participants and therefore conducive to cooperative and participative GI planning. This fosters local stakeholder appreciation of their landscape and its underlying environmental and ecological patterns and is inclusive of experts with from non-ecological disciplines. Hence, we would encourage the formal incorporation of algorithmic landscape models in Geodesign to address the following gaps as identified by Steinitz (2012) and to enhance the current state of the art of Geodesign:

- In representation models the application of Algorithmic Landscapes helps to deal with continuous, non-categorical information and fuzzy data. In particular, biophysical environmental phenomena usually do not have clear defined characteristics with well-defined borders. They are usually characterized by environmental gradients and landscape variables with smooth transitions.

- In process and impact models the application of algorithmic landscapes may help to understand interrelated systems, with complex attributes and interpret the interrelations in a simple and understandable manner according to the stakeholder interest.

- In the change models algorithmic landscapes offer a formal repeatable analytical methodology, transferable to different contexts.

2. Application Study

2.1. Habitat suitability modeling algorithms to identify spatial potentials for ecosystem functions and services

The second example uses algorithms for habitat suitability analysis. These support habitat- based conservation approaches, aiming to identify regions, areas or sites (depending on spatial scale) suitable for target species conservation. Such information is needed to support the planning of hubs, sites and links that are fundamental components of GI. Furthermore, these approaches can be used to identify spatial potentials for ecosystems and their services, highlighting areas with benefits for humans in general as well as those addressing the local stakeholders' interests.

The identification of spatial suitability for the development of GI components is essential for effective GI planning. Therefore, effective suitability mapping methodologies are needed. Modeling of habitat suitability, also often referred to species distribution modeling (SDM), environmental or ecological niche modeling offer a promising mapping approach using algorithms for sophisticated data exploration. The main idea of habitat suitability modeling is to estimate the spatial distribution of suitable habitat conditions, based on statistical relations between known distribution patterns and prevailing landscape and environmental parameters (Ahmed et al. 2015). This approach is particularly efficient in areas where real occurrence data are missing, and helps to provide an overview of the distribution potential habitats and ecosystems. Many different algorithms and toolboxes have been developed (e.g. Guisan and Zimmermann 2000, Hirzel and Le Lay 2008, PeterSON 2006). They have been widely used to answer ecological questions related to reserve design and conservation planning, impact assessment and resource management, ecological restoration and ecological modeling, risk and impacts of invasive species including pathogens, and to analyse effects of global warming on biodiversity and ecosystems (Franklin and Miller 2009).

Habitat suitability modeling can support planning processes in an effective manner, providing an analytical methodology that is transparent, repeatable and transferable, that can be integrated in Geodesign as process and impact models as well as change models.

In this application study, habitat suitability modeling was used to map the potential spatial distribution of low-intensity grassland systems (figure 2). The relevance of these to the support of multiple functions for urban green infrastructure has been accessed

(Rolf et al. 2018). With the support of the modeling process, spatial potential for low-intensity grassland farmland have been identified that could contribute to a number of services, These include the protection of biodiversity, the regulation of local urban climate and air quality problems due to abiotic connectivity and opportunities for recreation and human regeneration at the urban fringe for city dwellers.

2.2. Assemblage modeling algorithms to summarise comprehensive biophysical data

Our first example illustrates the principal use of algorithmic-based methods for summarising comprehensive biophysical data in providing the reference basemap for GI planning and facilitating the Geodesign collaborative approach. The same algorithms can adapted to mapping potential ecologically sustainable agricultural land-use.

Methods suitable for landscape character assessment are manifold (Wascher 2005). Those driven by human ('expert') interpretation are vulnerable to subjectivity, whereas approaches that are based on more statistical, automated analysis – with or without interpretative refinement – are more transparent and meet the scientific rigour of repeatability and statistical reliability (Jongman et al. 2006, Bunce et al. 2008). The latter are the "algorithmic" methods and take advantage of computation and "big GIS data". The latter are the "algorithmic" methods and take advantage of computation and "big GIS data". Algorithms that can handle multiple continuous environmental variables are needed to properly analyse these data and to summarise and map the spatial interplay among them.

In the 1980s, Australian national raster coverages of biophysical environmental variables were developed to support 'Environmental Domain Analysis' (EDA) as a geographically mapped multivariate cluster analysis of physical environmental regimes (Mackey 1996). EDAs have since been undertaken in many different natural and cultural landscapes, including Northern America (Coops et al. 2009), Europe (Metzger et al. 2005), New Zealand (Leathwick et al. 2003), Switzerland (BAFU GRID-Europe 2010). These have taken advantage of advances in technology and data quality. One of the latest is the European Landscape Classification (Mücher et al. 2010), using state of-the-art image processing technology to classify and segment high-resolution multi-band raster of various environmental variables, integrating climatic and topographical factors, soils, and land-use.

A more bio-centered approach goes beyond EDA by using SDMs to delineate ecosystems rather than environmental domains (Peters and Thackway 1998). Our example is taken from this work. Figures 3A and 3B are both algorithmic landscapes with the same suite of environmental variables as input. Figure 3A is the EDA produced using an algorithm similar to that of Mackey (Mackey 1996). Figure 3B uses a different but not much more complicated algorithm. The map was developed from 65 bird SDMs considered together. Each SDM raster cell's value is the probability of the species being present. The SDM raster stack is the input matrix for a Principal Components Analysis (PCA). The output is a low dimensional representation of the spatial variance in species composition ("species assemblage space"). Thus, this modeling approach contains the combined species assemblage 'view' of the environmental data rather than a naive classification of them. One nice advantage of this algorithm is that each raster cell is located spatially as usual but has the orthogonal PCA species assemblage space coordinates as well. The three most informative of these can be projected into perceptually uniform color space. In this case, the regionalization phase did not use image segmentation algorithms because those available then could not handle mosaics. Instead the fuzzy ecosystem map was used by expert local biogeographers as a guide to drawing boundaries (collaboratively!). Providing a legend for these fuzzy maps is a challenge although locals seem to have little difficulty interpreting them. Recent advances in graphics processing will no doubt be helpful in providing interactive legends and the days of the paper map are probably coming to an end.

This 'species-oriented' algorithm can use SDMs trained on any spatial phenomena linked to the environment. For example a cultural landscape in Central Europe was modeled from land use mapping, using landuses classes as "species". A landuse was considered sustainable from the point of view of local environmental regimes if its model was a good fit (Peters 1999, Rolf 2012). Similarly, expert maps of potential natural vegetation etc. can be "reverse engineered" using this approach to discover the rules the experts probably used and perhaps to reveal their underlying assumptions.

The products of these landscape classification and visualization algorithms can provide the reference basis for GI planning in that they help planners and stakeholders to understand landscape as an interrelated dynamic process of biological and physical factors. Further, the models can be readily integrated in the Geodesign as 'representation' models and might also be appropriate inputs for change models.

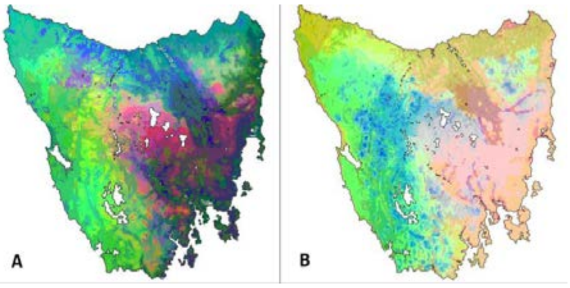

Figure 3. A: Environmental Domain Analysis, B: Species Assemblage Modeling. Both are 'algorithmic landscapes' and are based on analysis of the same suite of environmental rasters. Scale: Tasmania is 300km wide. Both maps have fuzzy boundaries. Perceived colour differences correspond to data differences for non-colour blind viewers. (adapted from Peters and Thackway 1998).

3. Conclusion and Outlook

We have highlighted the strength of Geodesign for GI planning if based on sound scientific ecological data. The integration of our suggested algorithmic landscape approach can contribute to this strength by enabling the ecological information to be summarised for communication with stakeholders with limited specialist ecological knowledge.

We realize that the general approach is not new and that geographic information science already offers a number of different algorithms that appear to be suitable for integration in Geodesign processes. However, we also note that as yet, no 'ready-to-use' solutions are out there. We believe that the time has come to introduce these into the GI planning mainstream.

Nevertheless, the examples provided by this work illustrate how the use of sophisticated algorithms help to analyse complex ecological interrelations in the landscape. Such approaches help to handle comprehensive environmental data and offer opportunities to process them purposefully. In particular, the examples attempt to demonstrate the potential of algorithmic landscapes to provide the baseline mapping of underlying environmental regimes, relevant to local ecosystems that we see as vital for GI planning.

More research effort is needed to strengthen ties between geographic information systems science and design and to demonstrate the utility of the approach. Still, we believe GI planning stands to benefit from algorithmic models incorporated in the Geodesign framework when it comes to the identification of potentials for ecosystem conservation along with their services and human benefits.

Despite the limitations of this work we hope it has shed some light on these potentials and that it will encourage discussion to further evaluate the use of algorithmic landscapes as part of the Geodesign framework. We believe that algorithmic landscapes can contribute to Green Infrastructure planning directly but can be even more effective when delivered as part of the Geodesign process. When all three components of our suggested approach are combined we can hope for effective communication to stakeholders of the complex ecological interrelations that need to be considered in the delivery of any viable GI plan.

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2.3. ARTICLE-III: A STAKEHOLDER APPROACH, DOOR OPENER FOR FARMLAND AND MULTIFUNCTIONALITY IN URBAN GREEN INFRASTRUCTURE

2.3.1. OVERVIEW

The article was published in Urban Forestry & Urban Greening. The results were presented at the ESP Europe regional conference 2018, 15.-19.10.2018 in San Sebastian, Spain.

The first author, WR developed the conceptual approach and conducted the participatory approach. Analysis of the data and writing of the manuscript was done by WR. All co-authors contributed to the manuscript by scientific advice and language editing.

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2.3.2. MANUSCRIPT

A stakeholder approach, door opener for farmland and multifunctionality in Urban Green Infrastructure.

Werner Rolf, Stephan Pauleit, Hubert Wiggering

Abstract

During the last years Urban Green Infrastructure (UGI) has evolved as a research focus across Europe. UGI can be understood as a multifunctional network of different urban green spaces and elements contributing to urban benefits. Urban agriculture has gained increasing research interest in this context. While a strong focus has been made on functions and benefits of small scale activities, the question is still open, whether these findings can be up-scaled and transferred to the farmland scale. Furthermore, multifunctionality of urban and peri-urban agriculture is rarely being considered in the landscape context. This research aims to address these gaps and harnesses the question if agricultural landscapes – which in many European metropolitan regions provide significant spatial potential – can contribute to UGI as multifunctional green spaces. This work considers multifunctionality qualitatively based on stakeholder opinion, using a participatory research approach. This study provides new insights in peri-urban farmland potentials for UGI development, resulting into a strategy framework. Furthermore, it reflects on the role of the stakeholder involvement for `multifunctionality planning´. It suggests that it helps to define meaningful bundles of intertwined functions that interact on different scales, helping to deal with non-linearity of multiple functions and to better manage them simultaneously.

1. *Introduction*

1.1. *Farmland as part of urban green infrastructure*

This paper examines the potential contributions of farmland to Urban Green Infrastructure (UGI) with emphasis on the key principle of multifunctionality using a qualitative approach. According to Hansen et al. (2017a) UGI planning can be understood as "a strategic planning approach that aims to develop networks of green and blue spaces in urban areas, designed and managed to deliver a wide range of ecosystem services and other benefits at all spatial scales." UGI planning contributes to policy objectives for sustainable urban development (Lafortezza et al., 2013; Mell, 2017; Pauleit et al., 2017), responding to environmental and social challenges, such as biodiversity conservation (e. g., Müller et al., 2010; Elmqvist et al., 2013), climate change adaptation (e. g., Bowler et al., 2010; Demuzere et al., 2014; Liu et al., 2015), green economy development (e. g., Simpson and Zimmermann, 2013; Andersson et al., 2016), and social cohesion (e. g., Thompson, 2002; Peters et al., 2010; Haase et al., 2017). Davies et al. (2015) summarise several key principles for successful UGI planning and implementation from the literature, such as connectivity, multifunctionality, integration and coordination of urban green with grey infrastructure, multiscale planning, as well as the design of strategic, cooperative and socially inclusive planning processes (c.f. Benedict and McMahon, 2006; Kambites and Owen, 2006; Ahern, 2007; Pauleit et al., 2011).

UGI can be diverse, consisting of a mosaic of different green spaces, from regional scale objects, such as urban and peri-urban forests or rivers and riverbanks, to local scale objects, like green roofs, greened walls or street trees (Bartesaghi Koc et al., 2016). However, although in many urban regions farmland is representing a higher share than other urban green structures such as parks or forests (Pölling and Born, 2015; Rolf et al., 2017) it is often neglected while looking for spatial and functional potentials contributing to UGI (c.f. Bartesaghi Koc et al., 2016). On the other hand agricultural landscapes decline by urban expansion in many metropolitan regions (Gardner, 1996; Döös, 2002; Hooke and Martín-Duque, 2012).

Examples exist, where agricultural land is already being considered as part of UGI, functioning as a green belt, corridor, or part of a green network (e.g. Consorti Parc Agrari del Baix Llobregat, 2004; Regione Lombardia, 2010; Timpe et al., 2015). Also, urban agriculture has gained increasing attention recently (Van Veenhuizen and Danso, 2007; Viljoen and Bohn, 2014; Lohrberg et al., 2016). However, considerably less attention has been given to farmland in and near urban areas. A strong research focus has been on small scale urban agriculture activities, such as urban gardening and their contributions to social benefits such as community empowerment (e.g. Mees and Stone, 2012; Drake, 2013; Classens, 2015) or food supply to support subsistence or health (e.g. Mok et al., 2014; Hartig et al., 2014; Horst et al., 2017; Martin et al., 2017). Some work also emphasize positive contributions to UGI functions and regulating effects such as reducing urban heat island or stormwater mitigation (e.g. Dunn, 2010; La Greca et al., 2011; Whittinghill and Rowe, 2012; Ackerman, 2012; La Rosa et al., 2014; Russo et al., 2017). However, there is reasonable doubt that these findings can be directly transferred in particular while upscaling from small scale urban agriculture activities to the farmland scale (c.f. Goldstein et al., 2016).

One reason why farmland on the large scale has not been a UGI research focus may be due to modern agriculture is primary being connoted causing conflicts, leading to negative impacts on human well- being in many regards (e. g. Tilman, 1999; Pretty et al., 2000; Kremen et al., 2002; Foley et al., 2005; Hooper et al., 2005; Stoate et al., 2009; Potts et al., 2010; EEA, 2013). But besides it is widely accepted that integrative approaches and concepts can play an important role to reconcile food production with the conservation of biodiversity and the promotion of ecosystem services for human benefits (e. g. Jackson and Jackson, 2002; Rosenzweig, 2003; Clements and Shrestha, 2004; Scherr and McNeely, 2007; Pollock et al., 2008; Foley et al., 2011).

In this context is has to be mentioned that 'land sharing' is currently debated as an integrated land use strategy, optimizing agroecological productivity while maintaining biodiversity and protecting natural resources in a 'shared' food production system as opposed to 'land sparing', which is intending a segregated land use strategy, optimising agricultural productivity while 'sparing' land for the conservation of biodiversity and natural resources (e.g. Green et al., 2005; Phalan et al., 2011; Tscharntke et al., 2012). In the meanwhile the discussion about land-sparing vs. land-sharing – formerly driven by conservation biology – has been reframed, looking beyond these two dimensions of food production and biodiversity, taking into account various societal demands as well (c.f. Grau et al., 2013; Fischer et al., 2014; La Vega- Leinert and Clausing, 2016; Bennett, 2017). However, it needs to be understood that these polarizing lenses – land use specification and land use diversification – should not be seen as a simple 'either-or' solution but need to be looked at in a spatial and systemic context. Benton et al. (2003) emphasize the relevance of heterogeneity of structures in the agricultural landscape on a range of spatial scales (from within individual fields to whole landscapes) influencing biodiversity benefits. Haber (1971) endorsed in the idea of 'differentiated land use' as an integrated approach for agricultural landscapes. Besides biological diversity, this concept emphasizes furthermore structural diversity and relates "food production with recreation, enjoyment of nature as cultural values" (own translation from Haber, 2014).

Thus, the potential of farmland contributing to UGI as a 'shared' or multifunctional agricultural food production system with other functions and benefits promoting societal health and human wellbeing becomes evident.

1.2. Multifunctionality as a key

Multifunctionality is not a new concept and has long been considered as an important management tool for sustainable agriculture and rural development (e.g. Wiggering et al., 2003; Mander et al., 2007; Renting et al., 2009). Thus, agri-environmental policy instruments and management tools promote multifunctionality by supporting the provision of different services with market or non-market values meeting society's demands, such as good agricultural and environmental standards for sustainable natural resource management, biodiversity conservation and animal welfare, or to stimulate the diversification of agrobusiness and production level, to regulate markets and to strengthen rural vitality (Kyösti and Kola, 2005; Sumelius and Backman, 2008; Renting et al., 2009; Casini et al., 2012). Ideas to advance policy instruments have been formulated promoting multifunctionality taking into account the broad range of ES explicitly (Plieninger et al., 2012; Galler et al., 2015; Holt et al., 2016; Landis, 2017). Van Zanten et al. (2014) even suggest an analytical framework to evaluate agricultural policies based on the ES. Recently the term of agrosystem service is being discussed, to emphasize the share of agricultural production to the supply of ES (Wiggering et al., 2016).

While looking at the peri-urban context farmland can serve very different functions and benefits, thus, contributing to multifunctionality. According to Mougeot (2000) agriculture "within (intra- urban) or on the fringe (peri-urban) of a town, a city, or metropolis" distributes diverse food and non-food products that contribute to the regional and local food supply to that urban area, as well as goods and services beyond food production such as management of cultural landscapes, leisure and recreational opportunities and other ES. In this regard, multifunctionality is seen as a diversification strategy for agricultural businesses and as an opportunity for agriculture to adapt to the urban situation (e. g. Ilbery, 1991; Bryant and Johnston, 1992; Zasada, 2011; Aubry et al., 2012; Zasada et al., 2013a,b).

In comparison to this research perspective, about business models and farm structures, this work rather harness multifunctionality as spatial concept, looking at the peri-urban landscape level. Therefore, it is important to understand that multifunctionality goes beyond the meaning about simultaneous spatial integration of different functions (Fig. 1). According to Selman (2017), it is a result of synergies between different functions in the whole landscape matrix and includes linkages with surroundings at different scales, considering adjacent neighbourhoods as well as the

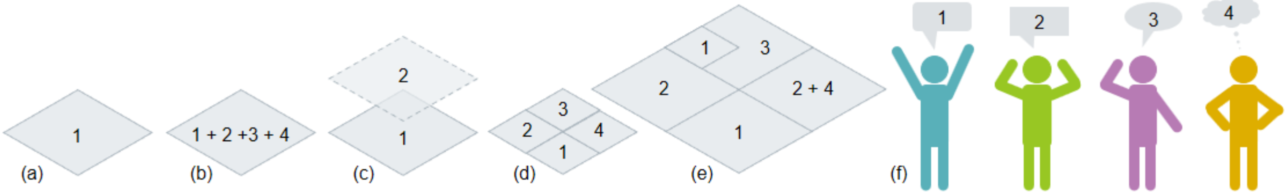


Figure 1. Multifunctionality concept in space and time (based and extended from Brandt and Vejre, 2004 and Selman, 2017): In comparison to monofunctionality (a), multiple functions can be supported in the same time and same place (b). Besides, different functions can be supported in the same place but in different times, often in certain cycles (c), such as green spaces that function as stormwater retention after heavy rainfall. Furthermore, different functions can be supported by different places that interact, thus providing multifunctionality spatially combined (d), whereas the space can differ in scale, depending on uses and interconnections. However, the valuation of multifunctionality always depends on the appreciation of the different functions by different stakeholder.

whole region. What's more, human appreciation of positive and negative interactions and functions is of high relevance, reflecting benefits from different perspectives and reconnecting social, economic, and environmental objectives. Consequently this work understands multifunctionality as an inter- and transdisciplinary spatial concept, that needs to take into account different appreciations and objectives, rather than summarising the number of functions solely, assuming 'as more the better'.

While management of multiple ES simultaneously are understood as important but "extremely challenging" (Bennett et al., 2009), in green infrastructure planning it is even being considered as one of the great challenges (Sussams et al., 2015; Hansen et al., 2017b). Luederitz et al. (2015) suggest stakeholder involvement to better contextualise ES, for better acceptance, to enhance plan implementation and engagement for management and maintenance. According to Bieling and Plieninger (2017) stakeholder involvement can be understood as a prerequisite for landscape stewardship as a "place-based, landscape-scale expression of broader ecosystem stewardship". Martín-López et al. (2012) demonstrate how participatory approaches help to identify social preferences to uncovering bundles of ES.

Concluding this, stakeholder involvement can be considered as crucial for an enhanced multifunctionality concept and to successfully develop strategies upscaling Urban Green Infrastructure (UGI) to farmland.

1.3. Aims and objectives of this study

Although several approaches investigating multifunctionality of agriculture in urban contexts exist, some limitations remain. First: urban agriculture as part of UGI is often being considered on a small scale leaving reasonable doubt that these findings can be directly transferred while upscaling to the farmland scale. Second: although in the last years research advanced the multifunctionality understanding of agriculture in peri-urban contexts regarding diversification of farming models and businesses, they mostly do not consider multifunctionality in the landscape context, a prerequisite for UGI planning. Consequently research on farmland as part of UGI appears fragmented while looking at the spatial urban scale. This study aims to address this gap. It consolidates and expands on works on urban agriculture and urban green infrastructure planning and raises the question how farmland can contribute to multifunctionality of UGI on the landscape level. To convey an understanding of multifunctionality that goes beyond a merely quantitative approach (summing up numbers of functions) this research has a focus on stakeholder valuations to promote multifunctionality in UGI considering farmland qualitatively.

Therefore this research addresses the following two research questions:

- What are potential contributions of peri-urban farmland to multifunctional UGI, based on stakeholder opinions?
- Which role takes the participation in the process of ´multifunctionality planning´?

Based on these findings we want to conclude further implications for UGI planning and research.

2. Data and methods

2.1. Study region

This research was conducted in the City of Malmö, in Sweden (Fig. 2) as one of the five European Urban Learning Labs (ULL) that has been created to facilitate knowledge exchange between research, planning practice, and policies, involving various stakeholders. It has been selected as an ULL because of representing a growing European urban region, being aware about the ongoing urbanisation process with challenges and opportunities for green infrastructure and provision of ecosystem services (van der Jagt et al., 2016). Since the mid-1980s the population number continuously increased by almost 100,000 people, from about 229,936 in 1985 to 328,494 in 2016 (City of Malmö, 2017a) and is being expected to grow by another 50,000 within the next ten years, until 2027 (City of Malmö, 2017b). According to the European Urban Atlas (2012) almost 45% of the municipality is occupied by urban fabrics, quite as much as being used by agriculture. About 6.5% can be assigned to urban green space, just about 2% to forests.

The agricultural landscape in Malmö "is mainly intensively used and only to a very limited extent accessible for recreation" (Delshammar, 2015). It can be roughly divided in two different landscapes, the 'Western flat plain landscape' and the 'Eastern hill landscape' (City of Malmö, 2003): The 'Western flat plain landscape' – 'Västra slättlandskapet' and 'Östra slättlandskapet' can be characterised by small habitat-rich primary large scale agricultural land with up to 80–90% arable land use management and few amounts of small habitats such as trees, shrubs and water ditches. The 'Eastern hill landscape' – 'Södra backlandskapet' and 'Norra backlandskapet' is a rather heterogeneous landscape with diverse topography. Arable land use covers about 60% of the surface area and is therewith significantly lower as in the western flat plane landscape. A high amount of semi natural grassland and grazing land and a variety of small habitat structures such as ponds and tree groves are to be found. Thus, these farmlands offer very different site specific potentials and constrains.

In past the City of Malmö purchased almost half of the farmland for urban expansion (Fig. 2b). Currently about 3,775 ha agricultural land is owned by the City of Malmö within its city boarders and adjacent municipalities. Most of it is leased to tenure farmers with agricultural agreements (Torgil Brönmark - Malmö City, Real Estate Department, 8 June 2017). However, to avoid urban sprawl, the current planning strategy is aiming at higher density urban development while developing multifunctional urban green spaces as part of the 'Green-Blue Plan', essentially leading to a compact and green city as manifested in the Malmö Comprehensive Plan (City of Malmö, 2014). Due to this compact growth strategy new goals need to be formulated for the city own farmlands – which essentially points out the demand for this case study, as an opportunity to develop ideas for innovative strategies.

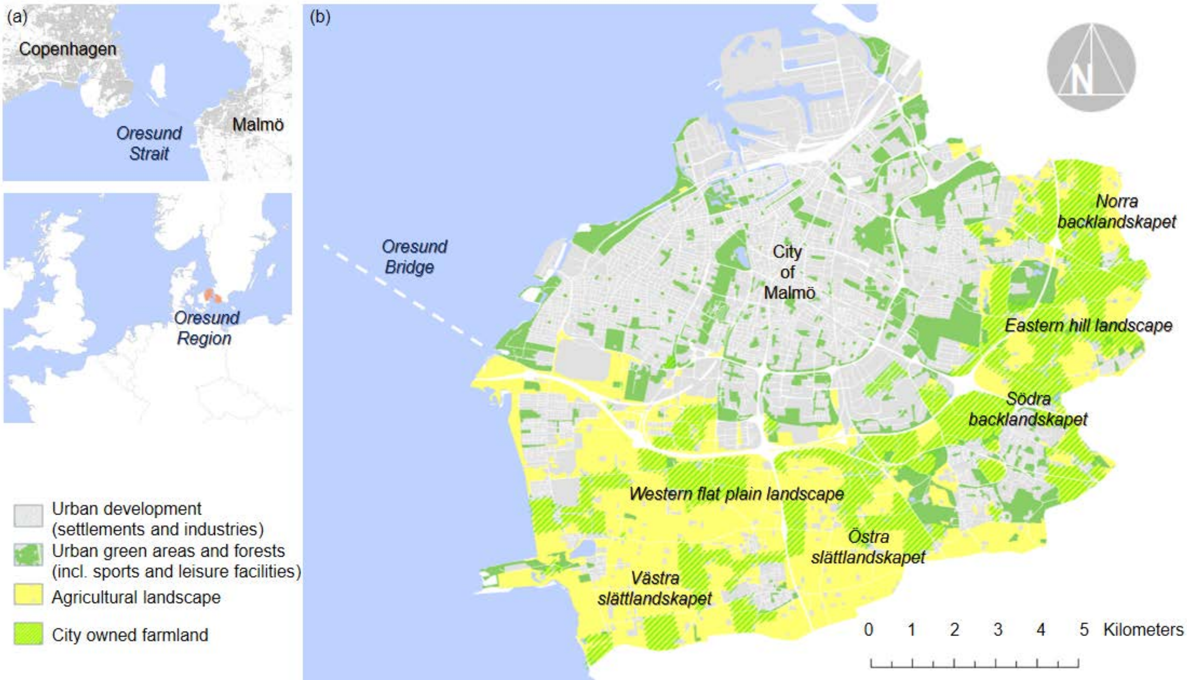


Figure 2. Malmö is located in the Oresund region and together with Copenhagen, Denmark it forms a transnational metropolitan area with about 4 million inhabitants (a). A significant amount of farmland within the city limits are owned by the City of Malmö (b). (Sources: Based on European Urban Atlas (2012), Geodata about owned farmland from the City of Malmö, state 2017)

2.2. *Stakeholder approach*

During this study, different stakeholders have been involved to identify different strategies and strategic objectives for multifunctional farmland for UGI. Therefore, a workshop was conducted as part of the so called 'Focal Learning Alliance' (FLA) of the ULL Malmö. The FLA was embedded in the so called 'double helix' approach within the GREENSURGE (van der Jagt et al., 2016) offering opportunities for knowledge co-production and innovation (Jasanoff, 2004; Voorberg et al., 2014) due to science-practice interaction (Fig. 3a). This interand transdisciplinary approach aims on a strong collaboration between researchers and local actors, leading to the involvement of multiple knowledge holders. Oscillating between 'knowledge creation' on the one hand and 'knowledge integration' on the other hand (c.f. Schneidewind, 2014) this 'learning alliance' helps to advance applicability of theoretical findings by 'hybrid' knowledge emerging from the different knowledge involved.

Within an early phase of the 'double helix', the so called 'process initiation phase', the need of new objectives for Malmö's city owned peri-urban farmland had been expressed by local stakeholders, which finally lead to this collaboration to initiate the development of innovative UGI strategies together with stakeholders (Rolf et al., 2016). The FLA workshop finally took place in the Malmö City Hall (Stadshuset), in June 2017. It was coordinated together with the city's streets and parks department, whose interest was driven by the need of innovative strategies and objectives for the city owned farmlands (Fig. 3b) to be implemented in the new 'Green-Blue Plan', currently under development.

To develop strategies and objectives that apply multiple purposes, ultimately 15 selected participants were involved in this workshop, representing a broad spectrum of all relevant stakeholder groups with different interests. These were representatives from various city departments involved in planning, like Streets and Parks, City Planning Offices and Real Estates, and further organisations, representing urban development, agriculture and farm tenure, open space planning, water resource management, recreation, cultural heritage and nature conservation.

The workshop consisted of presentations and moderated discussions indoors accompanied by a field trip visiting different agricultural sites. A main component of the workshop was the use of scenario techniques adapted from Nassauer and Corry (2004) (Fig. 3). Accordingly, in a first step, after a thought-provoking impulse on 'UGI objectives', potential contributions of farmland to protect biodiversity, promote ecosystem services, societal health and well-being were imaginatively selected, taking into account stakeholders different appreciations. Relating to these 'UGI objectives' in the second step desirable development trajectories for farmland and interventions were discussed. Based on these, in the third phase, the 'potential contributions of farmland' regarding the UGI objectives were predefined. To inspire innovative options it was important not to limit this part of the discussion to farmland characteristics currently existing in the Malmö region, but to take into account others, currently not being present, considering them all as 'desirable farmland characteristics'.

During all these three steps plausibility of relevance and their effects on different functions and benefits were evaluated by the dialog with and between the different stakeholders (i. e. knowledge

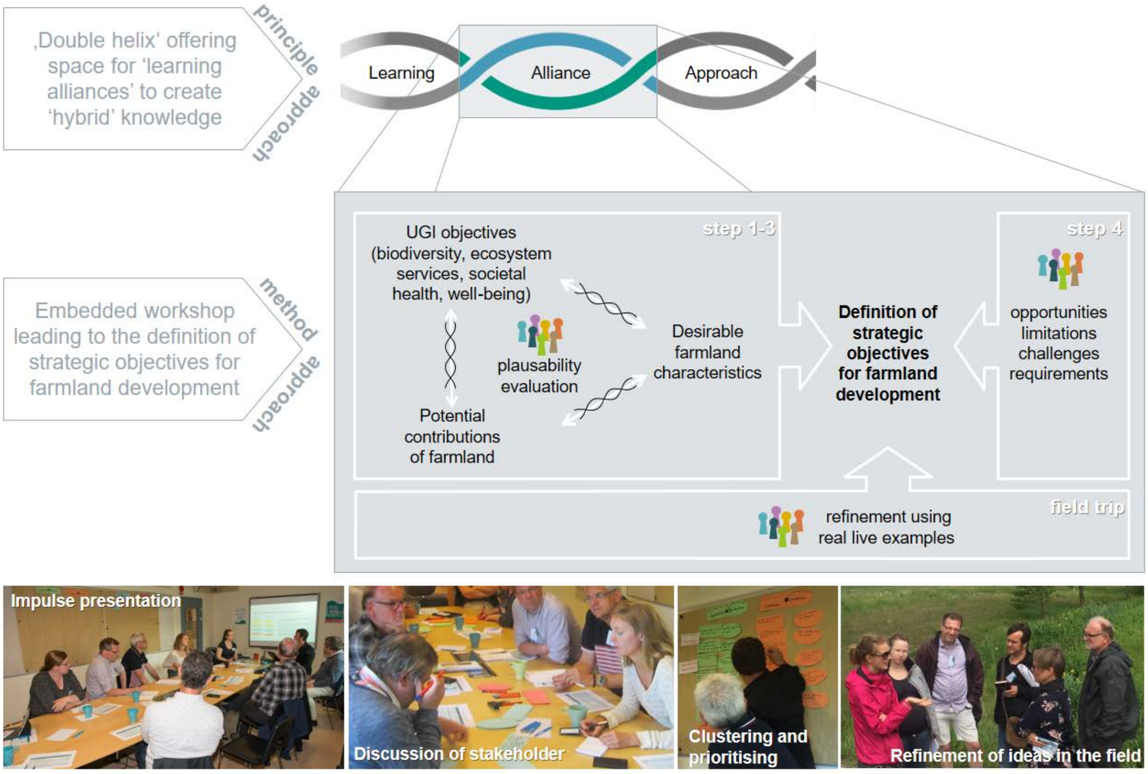


Figure 3: The workshop is embedded in the 'double helix' approach, promoting iterative knowledge exchange to develop 'hybrid' knowledge by incorporating knowledge and valuations of different stakeholders. Photos illustrate different working phases of the workshop. (Photos: Bendroth, Mårsén, Rolf,)

holders). Therefore it is important to discuss with an interdisciplinary team, representing different knowledge and valuations. Furthermore, these individual development trajectories and interventions i.e. 'desirable farmland characteristics' were reflected in step 4, considering the following questions:

- What are the 'opportunities' (potentials) if farmland becomes part of UGI?
- What are 'limitations' (hindering factors) to develop farmland as part of UGI?
- Which 'challenges' are we facing while developing farmland as part of UGI?
- What are 'needs' (requirements) to develop farmland as part of UGI successfully?

All informations and thoughts where gathered and thematically related aspects were clustered. Furthermore, priorities have been set on consensus among participants. Finally, 'strategic objectives for farmland development' were defined. Essentially, these 'strategic objectives' represent abstract conclusions of the individual cases of 'desirable farmland characteristics' discussed before, to enable transferability to other regional contexts.

In the second half of the workshop a field trip took place to crosscheck principle strategic objectives defined before within 'real live examples', taking into account different site-specific management options, to further reinforce and refine those strategies if needed. Therefore, different selected agricultural landscapes were visited. The visited sites were characteristic for the agricultural landscape of Malmö, taking into account variances of prevailing site conditions – high productive farmland in the Western flat plain landscape and low productive farmland in the Eastern hill landscape.

Finally, different strategies were evaluated regarding their benefit appreciations as discussed by the participants distinguishing between 'key functions', 'additional benefits' or 'no benefits' (Fig. 4).

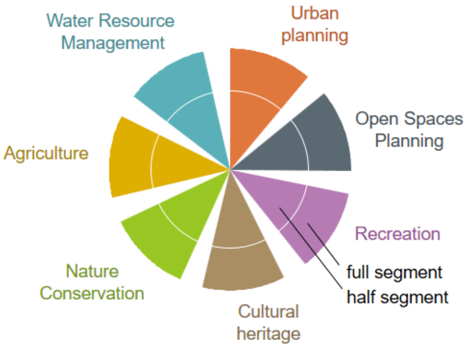


Figure 4: Polar area chart used for evaluation of different stakeholders benefit appreciation as discussed in the workshop; full segment indicates discussed key function, half segment indicates discussed additional benefits, no segment indicates no benefits discussed. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Figure 5: To maintaining agricultural productivity while facilitating multiple social functions on-site examples like rent-a-field farm or self-picking farm (here an example with 'berry café' at the northern urban fringe of Munich) were discussed by the participants. Such examples are not currently present in the Malmö region. Diagram illustrates main valuations on this principal strategy from stakeholder perspectives. (Photo: W. Rolf)

3. Results of the stakeholder approach

As one main result of this workshop the stakeholders agreed that there is no 'one size fits all' solution for farmland contributions to multifunctionality as part of UGI. Instead, strategies need to respond to site characteristics of the agricultural landscape and its agricultural productivity, taking into account site conditions such as soil, hydrology, and topography. Two main strategy strands have been identified by the participants, to assist multifunctionality on highly-productive farmland on the one hand, like in the 'Western flat plain landscape', and to assist multifunctionality on less-productive farmland, like in the 'Eastern hill landscape', on the other hand (see landscapes in the region as outlined in Fig. 2). These different, here identified strategy-strands and stakeholder-opinions will be presented in the following.

3.1. Identified strategies on highly-productive farmland based on stakeholder opinions

To address sites with high agricultural productivity, like in the 'Western flat plain landscape', the maintenance of this productivity was of very high preference among all participants. Literally all stakeholders understood the relevance to maintain productivity, mainly for two reasons: to promote local food production but also to strengthen partnership with the farmers. Two different options were discussed because of this: facilitating multiple functions on-site and implementation of complementary measures off-site.

Facilitation of multiple on-site functions can be achieved by combining entrepreneurial production with additional social benefits. These can be e.g. increased access for own food supply and leisure activities. Participants discussed options like self-picking-farms, which are tilled by farmers offering harvesting opportunities for citizens for fruit (e.g. bush berries, strawberries), vegetables (pumpkin fields) or flowers and farmland (partly) prepared by farmers and rent out to citizens in parcels (rent-a-field) offering individual cultivation measures for urban dwellers (Fig. 5). These options were seen as innovative business strategies for the farmers and as opportunities to diversify agricultural businesses in the region, in particular as such business models are currently not existing in the Malmö Region.

Consequently, one key function is paramount in this strategy, giving an implicit recognition to farmers by all stakeholders to maintain agricultural productivity and to gain economic benefit. Additional benefits considered are from the point of view of open space planning, urban planning and recreation, because of new opportunities for leisure activities, positively contributing to live quality of the urban environment.

Another possibility to develop multifunctionality in high-productive agricultural landscape was the implementation of complementary measures off-site, to support additional functions such as linear structures, connectivity and networks for citizens and biodiversity without interfering farming activities (Fig. 6). The participants primary have related key functions to open space planning and recreation, because of increased connectivity for leisure activities and recreational purposes, such as horse riding, cycling or walking. An extensive network was considered as an important contribution to enhance accessibility of the surrounding landscape for urban citizens. Representatives from nature conservation have seen additional benefits in particular, if margin strips are designed to provide habitat enhance connectivity for wildlife and promote dispersal in the agricultural landscape. If linear structures are in addition greened by pollard willows they are highly appreciated from cultural heritage perspective, because of reintroduction of such traditional landscape features that widely vanished due to intensification in the past. According to participants, farmers appreciate these networks too, if allowed to use them as farm tracks. Further benefits for agriculture may result, if margin strips provide habitat for pollinators, contribute to biological pest control or prevent soil erosion.

Fig. 6. Recently a horse riding path has been developed across highly productive agricultural landscape, contributing to a network for leisure activities and recreation in Malmö (right image). This measure has been widely accepted by farmers as this also improved accessibility to their own fields. During the workshop officials from different departments discussed how this situation can be further improved by integrating field margins with traditional pollard willows (left image), promoting additional ecological functions, like providing pollinator habitat, increased connectivity for wildlife, and preventing soil erosion in the same time. Diagram illustrates main valuations on this principal strategy from stakeholder perspectives. (Photos: W. Rolf).

3.2. Identified strategies on less-productive farmland based on stakeholder opinions

On sites with low agricultural productivity, like in the 'Eastern hill landscape', the interests for agricultural production often is lower. Participants discussed that this offers opportunities to prioritise other functions, such as promoting traditional agricultural land use to make benefit of its natural and cultural potentials for biodiversity, landscape heritage and citizens (Fig. 7). Examples discussed were semi-natural grasslands, (forest) pasture, and orchards. Although productivity can be maintained under the given constraints of the site's potentials, participants of the workshop assigned key functions to nature conservation and cultural heritage in particular as low-intensity farmland present traditional landscapes features contributing to natural and cultural diversity. Strongly linked with the maintenance and development of such

Figure 7: 'Robotfältet', partially used for military exercises, is a 110 ha large coherent area within few minutes cycling distance to residential areas in Malmö. This area is characterized by large extends of semi natural grasslands primary maintained by sheep grazing. It offers high potentials to protect biodiversity and represents agricultural landscape that has been developed by traditional land use but is nowadays threatened due to land use intensification. Promoting low-intensity farmland management is being considered as a preferable option to maintain biodiversity, the landscape character as a cultural value and its aesthetic values for recreation. However, up to now it is not integrated in a recreation network with signed paths and trails. Thus, its potential is currently not fully used. The diagram illustrates main valuations on this principal strategy from stakeholder perspectives. (Photo: W. Rolf)

Figure 8: Björkerlunda was identified as an already existing multifunctional farmland owned by the City of Malmö under low-intensity grazing management. It's of 16 hectares large in size and since 1999 about 4 hectares have been developed for water retention to reduce phosphorus and nitrogen load of surface water before released into the coastal sea. Today it is breeding habitat for about 14 bird species and a resting place for many others, such as the kingfisher. This area is regularly used by school classes from Malmö, for nature experience and environmental education. The diagram illustrates main valuations on this principal strategy from stakeholder perspectives. (Photo: Werner Rolf)

traditional landscapes, additional benefits were seen by stakeholders from urban planning, open space planning and recreation, because of opportunities for nature oriented leisure activities, contributing to live quality for urban dwellers, such as horse riding, cycling and walking. From the farmers perspectives possible benefits have been seen just to some extend and just in case farmland products can be linked with authenticity, related to the traditional landscape. Appropriate marketing strategies, aiming at city consumers may help to compensate low productivity of these sites.

In case of uneconomic agricultural usage of low productive sites with very few benefits, participants suggested a complete management shift and restoration as an option to develop new functions and benefits for biodiversity, urban environment and citizens. This could for instance result in multifunctional management of low-intensity farmland (Fig. 8). The example of 'Björkerlunda' illustrates such a case primary driven to serve functions for better water resource management, to regulate water flow and to enhance water quality.

From the farmers point of view agricultural production is of subordinate relevance. Nevertheless, regulating functions, in particular water resource management, can have paramount key function. Measures discussed may involve the development of retention basins, restoration of wetlands, conversion of arable land to grassland, and reduction of management intensity along stream margins and in riparian zones. Such measures were appreciated by other stakeholders too, as they help to enhance the quality for wildlife habitat or because of offering opportunities for nature experience, promoting recreation and environmental education. Because this requires specific farmland management measures, agricultural use would be still possible with some restrictions. Thus, strong incentives for farmers are considered as necessary.

4. *Discussion and conclusion*

The results of this study provide new insights into the potentials of peri-urban farmland contributing to UGI on the one hand and regarding the role that participation does have in this process on the other hand. To address the research questions we will focus the discussion and conclusion on two aspects: i) reflection on the farmlands potentials to UGI with emphasis on multifunctionality based on stakeholder opinions and ii) insights that emerge from this participatory approach for multifunctionality planning. Based on these reflection, implications for UGI planning and further research will be derived.

4.1. Potential farmland contributions to UGI based on stakeholder opinions

The results show some functions that agricultural landscape could assume on UGI according to stakeholders' opinion contributing to multifunctionality. However, it becomes clear that the functions depend on underlying conditions and landscape parameters. Thus, preferred functions can vary from situation to situation by one and the same stakeholder and some functions are considered as more relevant in some places than in others. Consequently, multifunctionality can look very different while looking across the whole agricultural landscape matrix.

For UGI planning this means, that it is necessary to define meaningful bundles of priority functions, comprising key functions and additional functions. This can help to avoid further land use competition in densifying urban areas (c.f. Hansen et al., 2017a,b). It also relates to the landscape approach according to

Sayer et al. (2013), and offers planning solutions that deal with land use competition while facilitating synergies between them.

Due to our results we herewith propose a draft of a framework on strategies and strategic objectives to develop farmland as part of UGI based on the stakeholder opinion, that considers site characteristics with impact on farmland productivity (Fig. 9).

According to this, UGI planning considering farmland has to bear the spatial and systemic context of the landscape matrix in mind instead of looking at single land plots negotiating either-or-propositions. Instead of considering multifunctionality on one and the same place solely, heterogeneity and structural diversity of peri-urban farmland seem to be a key to promote multifunctionality (c.f. Haber, 1971; Benton et al., 2003) for better UGI planning – at least while looking on the vast farmlands that often surround metropolitan areas across Europe.

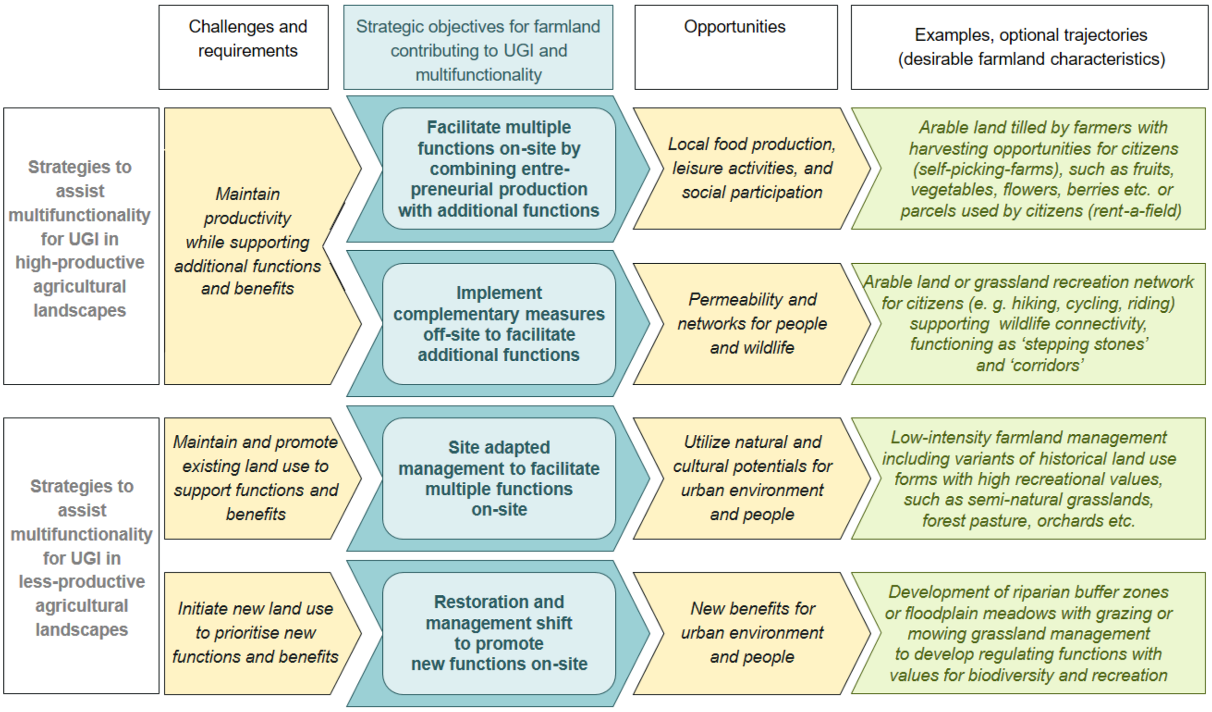
As a consequence, not all peri-urban farmlands need to be multifunctional per se or part of UGI, in particular because of monofunctional agricultural systems may still contribute to sustainable city development for instance to provide the large amount of local food demands for urban population (c.f. Wiggering et al., 2003).

Finally, implementation of strategies on farmland for UGI are crucial in particular because "ownership and tenure are fundamentally important aspects of UGI governance that affect how far active citizens, civil society organisations and businesses might be involved" (Ambrose- Oji et al., 2017). Because representatives of agriculture consider incentives for implementation at least in some cases as relevant, there is a need for verification of funding guidelines on various levels – European, national, federal, local.

Although the situation of farmland ownership in the case of Malmö is rather extraordinary, strategic objectives of this study may give meaningful impulses for strategy development in other regional contexts and different ownership structures. Therefore, we encourage to test the proposed strategies in further case study applications and other urban contexts involving further stakeholders, to enrich them by additional data from modelling, experiments and expert input to enhance and to refine them. In addition, further systematic reviews of scientific literature would help to gather a comprehensive evidence base about interrelations between farmland within urban contexts, synergetic effects, functions, and benefits as well as trade-offs that help to enrich the discussion.

4.2. The role of participation in the process of multifunctionality planning

Emerging from one aspect already mentioned in the section above – the negotiation of priority functions, comprising key functions and additional functions in meaningful bundles – the results clearly show, that multifunctionality can be an advocate for a site adequate use of landscapes, provoking win-win situations for both, the landscape and the users/stakeholders. It becomes evident that stakeholder participation helps to better contextualise functions with benefits for better acceptance, supporting plan implementation, management and maintenance. Hence, our findings are in line with recommendations by Luederitz et al. (2015) as well as findings by Bieling and Plieninger (2017). Already at the end of the workshop, participants agreed on further cooperation and planned to expand implementation of Malmö's 'Green-Blue Plan' to the agricultural landscape. In the meanwhile an evaluation by



	Challenges and requirements	Strategic objectives for farmland contributing to UGI and multifunctionality	Opportunities	Examples, optional trajectories (desirable farmland characteristics)
Strategies to assist multifunctionality for UGI in high-productive agricultural landscapes	*Maintain productivity while supporting additional functions and benefits*	**Facilitate multiple functions on-site by combining entrepreneurial production with additional functions**	*Local food production, leisure activities, and social participation*	*Arable land tilled by farmers with harvesting opportunities for citizens (self-picking-farms), such as fruits, vegetables, flowers, berries etc. or parcels used by citizens (rent-a-field)*
		Implement complementary measures off-site to facilitate additional functions	*Permeability and networks for people and wildlife*	*Arable land or grassland recreation network for citizens (e. g. hiking, cycling, riding) supporting wildlife connectivity, functioning as 'stepping stones' and 'corridors'*
Strategies to assist multifunctionality for UGI in less-productive agricultural landscapes	*Maintain and promote existing land use to support functions and benefits*	**Site adapted management to facilitate multiple functions on-site**	*Utilize natural and cultural potentials for urban environment and people*	*Low-intensity farmland management including variants of historical land use forms with high recreational values, such as semi-natural grasslands, forest pasture, orchards etc.*
	Initiate new land use to prioritise new functions and benefits	**Restoration and management shift to promote new functions on-site**	*New benefits for urban environment and people*	*Development of riparian buffer zones or floodplain meadows with grazing or mowing grassland management to develop regulating functions with values for biodiversity and recreation*

Figure 9: Suggested framework on strategies to assist multifunctionality for UGI in agricultural landscapes, depending on site characteristics i.e. productivity (depending on soil, topography, water conditions etc.)

van der Jagt et al. (2017) revealed, that this workshop has contributed to "one of the strongest outcomes of collaborating with GREEN SURGE", leading to new collaboration between officials from different city departments to improve quality of the peri-urban farmland in the Malmö Region. To further reflect on these processes and about outcomes in the region triggered by this approach and by the developed understanding on multifunctionality we suggest an ex-post evaluation to provide further insights about implementations on the ground, cooperative planning and cross-sectoral activities.

Emerging from our approach an inferential concept for cooperative UGI planning and cross-sectoral activities among stakeholders in multifunctional peri-urban farmland can be summarised as illustrated in Fig. 10. It suggests that a moderated and transparent discussion of interests and objectives on different functions and benefits helps to increase understanding, find overlapping interests and to foster joint activities.

Furthermore, we conclude two aspects at this point, based on the experience of this stakeholder participation and it's results, for future working hypothesis on multifunctionality as a planning concept:

i) Dialog with different stakeholders seem to work as a regulator, helping to mediate conflicts, to assess and minimize trade-offs, identify or even to actively develop synergies to better intertwine different functions. Hence, we suggest to understand multifunctionality as an iterative process, to deal with non-linearity of multiple functions and to better manage multiple functions simultaneously.

ii) The different lenses of the stakeholders and their individual valuations of benefits can vary spatially and may be perceived as benefits on site, on adjacent sites, in neighbouring areas or even for the whole region. Hence, we suggest that multifunctionality benefits from the landscape context to promote intertwined functions that interact on different scales.

Both aspects support new 'hybrid' knowledge and a better understanding about interrelations of different functions, not just because of the different disciplines and stakeholder interests but also because of collaboration between researchers and local actors (c. f. Jasanoff, 2004; Voorberg et al., 2014).

Herewith, the multifunctionality concept turns out to become the basis for a new quality within the decision finding and making process. Thus, results suggest that an enhanced multifunctionality concept can be an essential planning and participation tool within the ambitions to up-scale UGI to farmland.

Therewith, this work gives hints for further development about the multifunctionality concept in general, still being considered as one of the main challenges for successfully UGI planning (c.f. Sussams et al., 2015; Hansen et al., 2017a, b). However, several questions may arise while looking closer on aspects that have been just briefly discussion here. E.g. further integrative, inter- and transdisciplinary research may yield outreached assessment opportunities within a decision support approach, to implement the multifunctionality concept more efficient.

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2.4. ARTICLE-IV: INTEGRATING FARMLAND IN URBAN GREEN INFRASTRUCTURE PLANNING – AN EVIDENCE SYNTHESIS FOR INFORMED POLICY MAKING

2.4.1. OVERVIEW

The article was published in Land Use Policy. The results of this paper were presented at the IALE World Congress 2019, 1.-5-.7.2019 in Milan, Italy.

The first author WR developed the methodological framework and research design. All policy document analysis and scientific literatures review, including the evidence synthesis was done by WR. KD supported the discussion of the analysis results with regard to the science-policy-interface. All other co-authors contributed to the manuscript by scientific advice and language editing.

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2.4.2. MANUSCRIPT

Integrating farmland in urban green infrastructure planning – An evidence synthesis for informed policymaking.

Werner Rolf, Katharina Diehl, Ingo Zasada, Hubert Wiggering

Abstract

The Green Infrastructure (GI) Strategy was adopted by the European Commission in 2013, to promote the deployment of GI by integrating it into main policy areas. Despite a high level of awareness for a policy integration across sectors at the EU level, urban and peri-urban farmland (UPUF) is up to now barely considered. A systematic evidence base addressing the contributions of UPUF can support a more informed policymaking. To address this, our paper developed a first evidence synthesis, to evaluate potential of UPUF contributing to policy objectives, thereby tackling major urban challenges. Furthermore an analysis of policy documents revealed gaps on the current state of policymaking and potentials for the integration in future policies. Due to a reciprocal consideration between EU level policies and scientific knowledge this work provides information that help to further construct scientific evidence to address policy concerns while taking into account multiple perspectives. Furthermore, we discussed the implications of our findings for further UGI research and policymaking and thus hope to extend the current political debate across policy sectors.

1. *Introduction*

1.1. *Urban Green Infrastructure and the urban and peri-urban farmland*

Green Infrastructure (GI) has been developed as a spatial planning and design concept for urban, peri-urban and rural areas (Benedict and McMahon, 2006; Kambites and Owen, 2006; Ahern, 2007; Mell, 2010; Rouse and Bunster-Ossa, 2013). In 2013, the European Commission adopted the European GI Strategy, as part of the six main targets of the EU Biodiversity Strategy to 2020 (European Commission, 2011), defining GI as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services […] present in rural and urban settings” (European Commission, 2013a,b). It aims to promote GI in the main policy areas, “to create an enabling framework to encourage and facilitate GI projects within existing legal, policy and financial instruments” (ibid.).

Particularly in the urban environment, this is believed to provide benefits that link to provisioning, regulatory and cultural ecosystem services and could help tackling major challenges of urbanisation related to human well-being. Urban Green Infrastructure (UGI) in functional urban areas1, is being considered as a promising approach for sustainable urban development (e.g. Lafortezza et al., 2013; Mell, 2017; Pauleit et al., 2019). It was found to contribute to tackle major urban challenges, such as biodiversity conservation (e.g. Elmqvist et al., 2013), climate change adaptation (e.g. Demuzere et al., 2014) due to temperature regulation (e.g. Bowler et al., 2010) and storm water reduction (e.g. Liu et al., 2015). Furthermore it was found to increase social cohesion by providing social space (e.g. Thompson, 2002), to support social interactions (Peters et al., 2010), and to promote the transition to a green economy (c.f. Simpson and Zimmermann, 2013). However, the empirical evidence for functional links between urban and green space elements and human benefits is scarce when it comes to urban and peri-urban farmland (UPUF) (Table 1). UPUF takes into account all of the utilizable agricultural land within the functional urban area. This includes all forms of extensive and intensive agricultural farming methods, may it be assigned to urban and peri-urban agriculture (UPUA) as defined by Mougeot (2000) in the narrow or wider sense, but also agricultural forms that do not intentionally supply any resources, products or services to the urban area nor do they appear to do so.

The lack of empirical evidence may come as no surprise to spatial planners, as “the urban–rural dichotomy is deeply ingrained in planning systems” (Allen, 2003) and UPUF are overall poorly considered in European planning frameworks (c.f. Errington, 1994; Scott et al., 2013). The specialization and intensification of agriculture, and not least its need to consume vast areas of land, has led to an increasingly clearer division between urban and rural areas. This development is certainly linked to a number of disservices and negative effects associated with agricultural land use and food production (e.g. Tilman, 1999; Foley et al., 2005; Stoate et al., 2009; Emmerson et al., 2016).

On the other hand, and to overcome such negative effects of agricultural land use, new spatial planning approaches are postulated, that balance food production and environmental outcomes both in rural and urban surroundings, by e.g. land sparing, land sharing and green infrastructure (e.g. Foley et al., 2011; Weltin et al., 2018). In the context of analysing the potential to interweave agricultural land use "back" into the urban environment, the potential contributions of the UPUF with regard to UGI objectives and related ecosystem services have to be looked at in a systematic way, in order to better support planning and policymaking. As yet, mainly small-scale UPUA activities, such as rooftop, allotment or community gardening, have been investigated in more detail, suggesting 'edible green infrastructure' as a nature-based solution that combines food production systems with positive effects on the urban environment (e.g. Horst et al., 2017; Lin et al., 2015; Buijs et al., 2016; Raymond et al., 2017; Artmann and Sartison, 2018). Other small-scale experiments and models show more potentials in the context of climate change adaptation such as cooling, absorption of pollution and the reduction of storm runoff (e.g. Shudo et al., 1997; Qiu et al., 2013). However, clear statements based on projected upscaling of such findings are difficult to make due to the complexity of interlinked factors like airflow (Ennos et al., 2014; Goldstein et al., 2016). Then again, multifunctionality of UPUA has been a subject of much interest in research (e.g. Mougeot, 2000; Van Veenhuizen and Danso, 2007; Pearson et al., 2010; Viljoen and Bohn, 2014; De Zeeuw and Drechsel, 2015; Rogus and Dimitri, 2015; Lohrberg et al., 2016; Sanz Sanz et al., 2018), revealing interlinkages to UGI objectives, such as social functions, recreational values and urban climate regulation. Besides these research findings, practical examples suggest that UPUF can be an essential part of UGI, like in Barcelona (Consorci Parc Agrari del Baix Llobregat, 2004), Frankfurt (Sterly and Mathias, 2016; Knickel et al., 2016) or Milan (Regione Lombardia, 2010). In all three cases the UPUF is an integral part of strategic planning, generating benefits in the urban space through the development of agricultural parks and green belts. In addition other integrative planning approaches and instruments have shown that UPUF can play an important role to integrate basic and applied ecology by considering multifunctionality, connectivity and heterogeneity, and thus revealing linkages with UGI planning principles (Muñoz-Rojas et al., 2015; Landis, 2017; Burton et al., 2019). We therefore believe, that a systematic evidence base addressing the contributions of UPUF to UGI objectives promotes a more informed policymaking in this respect.

1.2. The integration of GI at European policy level and the role of UPUF

The aim to promote GI across policy sectors as outlined in the European GI strategy (European Commission, 2013a,b), is strongly related to support regional development, climate change and disaster risk management, as well as natural capital, such as land and soil, water and nature conservation (ibid.). This idea has always been considered as essential, ever since debate "Towards Green Infrastructure for Europe" started and was seen particularly important in regard to climate change adaptation policies for urban areas, e.g. for improved water retention or temperature regulation, in regard to the Common Agricultural Policy (CAP) and also rural socio-economic policies (Sundseth and Sylwester, 2009). A number of studies in the meanwhile deepened the understanding about policies of relevance (Table 2). Furthermore, studies show linkages between ecosystem services and GI (EEA, 2011; Schleyer et al., 2015). The 'Habitats Directive' (Council Directive 92/43/EEC of 21 May 1992), together with the 'Birds Directive' (Directive 2009/147/ EC of 30 November 2009), building the European Natura 2000 network, now constitute the backbone of a Trans-European, being considered as strategic cornerstones of GI. Furthermore, the 'Water Framework Directive' (Directive 2000/60/EC of 23 October 2000) together with the 'Floods Directive' (Directive 2007/60/EC of 26 November 2007) are associated to water-related (blue) GI. In addition, the relevance of CAP (CAP, Reg 73/2009) was found beneficial in several ways (Mazza et al., 2011). The relevance of agricultural policy for GI development has been underpinned by EEA (2011), by promoting multifunctionality of farmland, taking into account biodiversity, recreation and water management. Furthermore, measures of agricultural policies have been identified that support the development of GI features and elements (Marsden and Jay, 2017), such as 'Greening' measures (CAP Pillar 1–1307/2013) and agri-environment measures (CAP Pillar 2 - EU regulations 1305/2013).

Besides, several studies shed light on the effect of European policies on UPUA, postulating the need of CAP to tailor incentives to regional and local objectives among others (e.g. Lohrberg

Table 1. UGI can be linked to provisioning services (food (PS1), raw materials (PS2), fresh water (PS3)), regulating services(local climate and air quality regulation (RS1), carbon sequestration and storage (RS2), moderation of extreme events (RS3), waste-water treatment (RS4)), and cultural services(recreation and mental and physical health (CS1), tourism (CS2), aesthetic appreciation and inspiration for culture, art and design (CS3), spiritual experience and sense of place (CS4)) (own illustration adapted and based on Haase et al. 2014 and Cvejić et al. 2015)

UGI typology with 8 groups (clustering in total 44 different classes)	provisioning services			regulating services				cultural services			
	PS1	PS2	PS3	RS1	RS2	RS3	RS4	CS1	CS2	CS3	CS4
building greens (e.g. green roofs, green walls)	■			■		■	■	■		■	
UGS connected to grey infrastructure (e.g. tree alley, street green, house garden)	■			■	■	■	■	■		■	■
riverbank green								■			
parks and recreation (e.g. urban park, pocket park, cemetery)	■			■				■			
alloments and community gardens	■							■			■
agricultural land (e.g. arable land, grass land, tree meadow/orchard)	■										
natural, semi-natural and feral areas (e.g. forest, shrubland, bog)	■	■		■	■	■	■	■	■		■
blue spaces (e.g. lake, pond, river, stream, canal)	■							■			

et al., 2016; McEldowney, 2017; Piorr et al., 2018). For example, CAP Pillar II funding is purely designated to rural areas. Thus, urban farmers are formally excluded from funding (Piorr et al., 2018). However, the overall interplay between European level policies, national, regional and local polices to promote UPUA are considered complex and multifaceted. Furthermore, sector-related EU level policies lead to missed opportunities due to inflexibility and thus are not well adapted to local circumstances (Curry et al., 2014).

Table 2. Current EU policies that have previously been considered as relevant for GI (adapted based on Atecma et al. 2010; Naumann et al. 2011; Mazza et al. 2011; Schleyer et al., 2015; Marsden and Jay, 2017)

Biodiversity and Nature Policies

- **Habitats Directive (1992)** – Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora
- **Birds Directive (2009)** – Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds
- **Life Programme (2013)** – Regulation (EU) No 1293/2013 of the European Parliament and of the Council of 11 December 2013 on the establishment of a Programme for the Environment and Climate Action (LIFE) and repealing Regulation (EC) No 614/2007 Text with EEA relevance
- **Biodiversity Strategy (2011)** – Communication from the Commission: Our life insurance, our natural capital: an EU Biodiversity Strategy to 2020 (COM(2011) 244)
- **Thematic Strategy for Soil Protection (2006)** – Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - Thematic Strategy for Soil Protection [SEC(2006)620] [SEC(2006)1165] (COM/2006/0231 final)
- **Environment Action Programme to 2020 (2013)** (Decision No 1386/2013/EU of the European Parliament and of the Council of 20 November 2013 on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet' Text with EEA relevance)

River and Water Policies

- **Water Framework Directive (2000)** – Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy
- **Floods Directive (2007)** – Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (Text with EEA relevance)
- **European Water Scarcity and Droughts Policy (2007)** – Communication from the Commission to the European Parliament and the Council on addressing the challenge of water scarcity and droughts in the European Union. COM (2007) 414 final, Brussels
- **Future Water Blueprint (2012)** – Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A Blueprint to Safeguard Europe's Water Resources (COM/2012/0673 final)
- **Nitrates Directive (1991)** – Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC)
- **Marine Strategy Framework Directive (2008)** – Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)
- **Marine Spatial Planning Strategy (2014)** – Directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning
- **Integrated Costal Zone Management (2002)** – Recommendation of the European Parliament and of the Council of 30 May 2002 concerning the implementation of Integrated Coastal Zone Management in Europe
- **Maritime and Fisheries Policy (2014)** – Regulation (EU) No 508/2014 of the European Parliament and of the Council of 15 May 2014 on the European Maritime and Fisheries Fund and repealing Council Regulations (EC) No 2328/2003, (EC) No 861/2006, (EC) No 1198/2006 and (EC) No 791/2007 and Regulation (EU) No 1255/2011 of the European Parliament and of the Council

Forest Policies

- **Forest Strategy (2013)** – Communication from the Commission: A new EU Forest Strategy for forests and the forest-based sector (COM/2013/0659 final)

Policies in rural and urban areas

- **Common Agricultural Policy and Rural Development Regulation (2013)**
  - Regulation (EU) No 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005
  - Regulation (EU) No 1306/2013 of the European Parliament and of the Council of 17 December 2013 on the financing, management and monitoring of the common agricultural policy and repealing Council Regulations (EEC) No 352/78, (EC) No 165/94, (EC) No 2799/98, (EC) No 814/2000, (EC) No 1290/2005 and (EC) No 485/2008
  - Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009
  - Regulation (EU) No 1308/2013 of the European Parliament and of the Council of 17 December 2013 establishing a common organisation of the markets in agricultural products and repealing Council Regulations (EEC) No 922/72, (EEC) No 234/79, (EC) No 1037/2001 and (EC) No 1234/2007
- **Regional Policy / Cohesion Fund (2013)** – Regulation (EU) No 1300/2013 of the European Parliament and of the Council of 17 December 2013 on the Cohesion Fund and repealing Council Regulation (EC) No 1084/2006
- **Urban Strategy (2006)** – Communication from the Commission of 11 January 2006 on a thematic strategy on the urban environment. COM(2005) 718 final – outdated!

Climate policies

- **Renewable Energy Directive (2009)** – Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC
- **Climate Change Adaptation Strategy (2013)** – Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. An EU Strategy on adaptation to climate change. COM(2013) 0216 final

Mobility and Infrastructure Policies

- **TEN-T trans-European transport network (2013)** – Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU
- **TEN-E trans-European energy infrastructure (2013)** – Regulation (EU) No 347/2013 of the European Parliament and of the Council of 17 April 2013 on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009

Spatial Planning Policies

- **European Spatial Development Perspective (1999)** – ESDP, European Spatial Development Perspective Towards Balanced and Sustainable Development of the Territory of the EU, Committee on Spatial Development
- **ESPON 2020 Cooperation Programme (2016)** – European Spatial Planning Observation Network Programme, revised version of the ESPON 2020 Cooperation Programme adopted on the 26 May 2016 by the European Commission
- **Territorial Agenda of the EU 2020 (2011**) – Territorial Agenda of the European Union 2020 Towards an Inclusive, Smart and Sustainable Europe of Diverse Regions as agreed at the Informal Ministerial Meeting of Ministers responsible for Spatial Planning and Territorial Development on 19th May 2011 Gödöllő, Hungary

Impact Assessment, Damage Pevention and Remediation Policies

- **Strategic Environmental Assessment Directive (2014)** – Directive 2014/52/EU of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment Text with EEA relevance
- **Environmental Liability Directive (2004)** – Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage

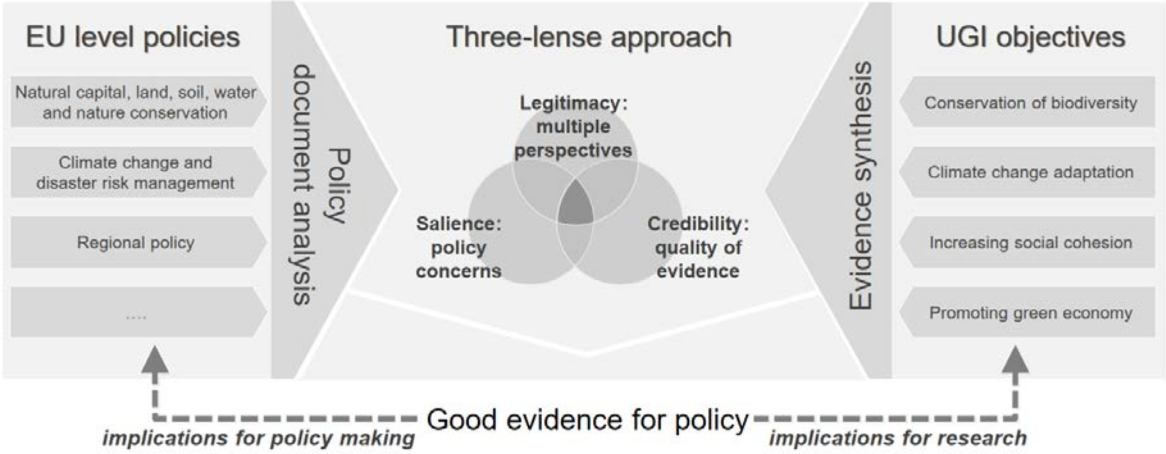

Figure 1. Underlying three-lense approach, guiding this work.

To summarise previous existing studies, although there has been a high level of awareness for a deep policy integration of GI across sectors at the EU level, EU level policies do not promote agriculture in an explicit urban context, thus not supporting UPUF as part of UGI. Still, a number of different EU level policies show indirect linkages to UPUF of relevance for the implementation of the EU GI strategy (Table 2).

1.3. *Aims and objective of this study*

Although the understanding of UGI has matured in past decades as a spatial planning and design concept for sustainable urban development, it needs to be endeavoured to ascertain the reasons why the contributions of UPUF are rarely considered. Also, the question arise why policy relevant scientific evidence addressing UPUF in UGI context is still fragmentary. Both aspects appear to be relevant, because they reveal missing linkages in the aims of the European GI strategy to promote GI in major policy areas at European level.

This leads to the following research questions: How does the current development of future European level policies promote UPUF supporting UGI objectives? How does scientific research with regard to UPUF support evidence-based policymaking?

For reciprocal consideration between EU level policies and scientific evidence this study aims to i) evaluate current steps at the EU level to further promote the European GI strategy in policies with emphasis on UPUF, ii) develop a first synthesis of current research outcomes, highlighting the benefits of UPUF contributing to UGI objectives and iii) identify potentials for evidence-based policymaking.

2. *Research approach, materials and methods used*

2.1. *Guiding principles for research approach*

To effectively link evidence with EU policies we followed up upon the idea of good evidence for policy (c.f Parkhurst and Abeysinghe, 2016; Parkhurst, 2017).' Good' or 'appropriate evidence for policy' is not just of high scientific quality but is available in ways useful to address key policy concerns at hand, and is applicable in this context. Adopting principles related to the model of credibility, salience and legitimacy (Cash et al., 2002) we relate a three-lense approach within our working steps to address the following aspects:

i) We captured the policy concerns to construct evidence by screening EU level policies in preparation of the EUs long-term budget 2021–2027 (as a proxy for salience).
ii) We took into account multiple perspectives while looking at evidence using multi criteria analysis (as a proxy for legitimacy).
iii) We warranted transparency, quality, rigour and validity of evidence by assessing the quality of science with regard to of UPUF benefits supporting different UGI objectives (as a proxy for credibility).

These three lenses helped to align research with policy concerns while conducting analysis of both: policy documents and evidence synthesis. Essentially, by identifying, analysing and setting our results into the context of 'good evidence' for policymaking helped to purposefully derive implications for informed policymaking on the one hand and implications for research to enhance a supportive evidence base on the other hand (Fig. 1).

2.2. *Conducting policy document analysis*

EU policy document analysis was conducted to evaluate current developments on integration of the European GI strategy in upcoming policies at European level, with emphasis on UPUF. As a proxy for salience this also helped to better construct evidence later on. This included on the one hand the follow-up of previous considerations and plans of policy implementations. Furthermore, it enabled the identification of new EU level policy arrangements, with potentials for future implementations. Our focus was on policy developments affecting the upcoming policy period related to the EUs long-term budget 2021–2027 (European Commission, 2018a, 2018b, 2018c). To do so we conducted a broad document analysis by using EUR-Lex database2 . EUR-Lex helped to follow up procedures leading to the adoption of legal acts and also to identify considerations and discussions about future policies besides already existing frameworks. The document analysis started 2015 just after the election of the new European Commission with its commissioners to cover policy making during 8th legislative session (2014–2019) and ended with the year 2018 just before document analysis was conducted for this work. It covered all preparatory documents of the European Commission, including legislative proposals, legislative and budgetary resolutions and initiatives, positions and opinion papers. Furthermore, it included commission documents, such as communications, reports, green and white papers and commission staff working documents of various kinds. Thus, this analysis covered different phases of the ‘policy circle’, such as during agenda setting over policy formulation, implementation and evaluation (c.f. Cairney, 2016).

The document analysis in EUR-Lex considered all documents within the Domain: ‘EU law and case-law’, Subdomain: ‘Preparatory documents’, within the timeframe from: ‘01/01/2015' to ‘31/12/2018' whereas ‘corrigenda versions’ had been excluded. The used terms and boolean operators, including wildcards for truncation options (*), for the text search query are: “green infrastruct*” OR “blue infrastruct*” OR “*urban agricult*” OR “*urban farm*” OR “*city farm*”.

To evaluate the relevance, a number of criteria were employed:

- Did the document explicitly mention “green infrastructure’?
- Dids the document explicitly relate to the “European GI strategy”?
- Did the document explicitly mention UPUF?
- Did the document relate either GI and/or UPUF to any EU policy objectives?
- Did the document relate either GI or UPUF to any European policies, strategies, programmes?
- Did the document relate either GI or UPUF to any new, potential initiatives at European level?

2.3. Conducting evidence synthesis

Evidence synthesis was conducted to give an overview of current research outcomes, highlighting the benefits of UPUF contributing to UGI objectives. The different phases of evidence synthesis are outlined in Fig. 2.

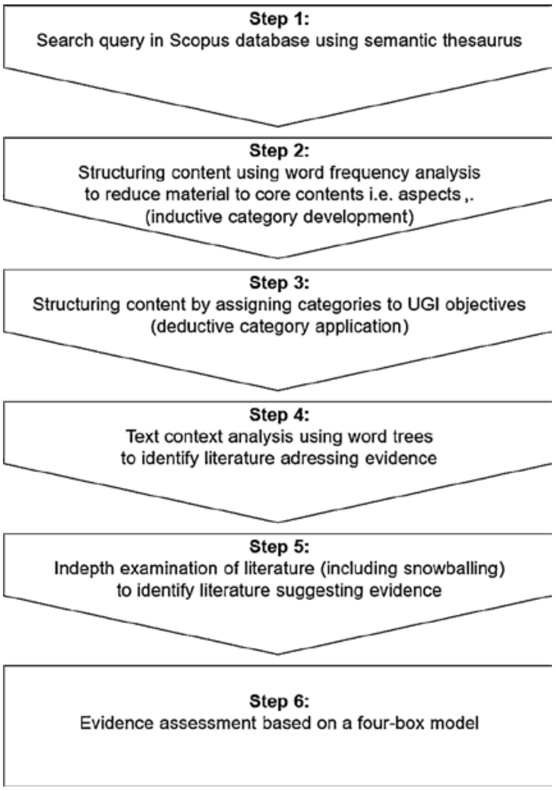

Figure 2. Overview on different phases of evidence synthesis conducted in this work.

Methodological approaches of evidence synthesis are very diverse and have been developed primary for healthcare science (e.g. Khan, 2011), but evolved in the meanwhile for nature conservation, environmental science, natural resource and environmental management (e.g. Cook et al., 2017; Livoreil et al., 2017; Webb et al., 2017). Because the UGI-context deals with complex situations and different objectives that may be valued differently within the decision making process (c.f. Pullin et al., 2016), we used multi criteria analysis as a methodological approach. This allowed to consider multiple perspectives, functions and benefits, thus comprising ecological, economic and social issues, thus functioning as a proxy for legitimacy. To ensure scientific rigor as a proxy for credibility, we used literature indexed in the Scopus database, which covers a wide range of peer-reviewed scientific journals (step 1). To identify relevant literature, a series of queries was conducted on reviews and articles from the years 2000–2018. We used a semantic thesaurus to convey the terms “urban”, “agriculture” “farmland”, “functions”, “benefits”, “ecosystem services”, using wildcards for truncation options (*) including boolean operators (AND, OR). The Scopus coded search query was defined as:

(TITLE-ABS-KEY (*urban*) AND TITLE-ABS-KEY (*agricult* OR *farm*) AND TITLE-ABS-KEY (*function* OR *benefit* OR *service*)) AND DOCTYPE (ar OR re) AND PUBYEAR > 1999 AND PUBYEAR < 2019)

In this first step the research question was widely defined, to receive a thematically focused but still broad collection of research items. Therefore in the second step it was necessary to structure and further optimize the literature finding for the multiple criteria analysis. Therefore we used NVivo software package (version 11). NVivo is a software for computer-assisted qualitative data analysis (c.f. Hoover and Koerber, 2011; O’Neill et al., 2018). It facilitates analysis of large amount of data and was used to inductively and deductively limit the literature to relevant articles, using word frequency analysis and word trees. For the second step all articles identified in Scopus were indexed in NVivo, including their attributes title, abstract, keywords, authors, journal (incl. volume, issue) year of publication, and citation count. Word frequency analysis (step 2) was used to structure articles and to reduce the documents to core aspects of relevance for our multiple criteria analysis and to consider multiple perspectives, comprising ecological, economic and social issues (functions/benefits/services). Therefore we explored the article attributes title, abstract and keywords, excluding meaningless terms and by merging terms with similar meanings and the same word stem. Then we gradually narrowed down the identified literature by deductively selecting terms that can be assigned to the four UGI objectives (step 3), such as on biodiversity (e.g. habitat, species, connectivity), climate change (e.g. cooling, stormwater, adaptation), social functions (e.g. participation, recreation, inclusion) and green economy (e.g. business, employment, footprint). To further examine documents, we used word trees in the next step (step 4). In NVivo word trees helped to explore the text contexts in which the keywords and phrases occur. Based on this, we further investigated relevant documents in more detail (step 5). According to the above mentioned criteria for relevance, we consider documents as relevant if they provided insights on UPUF with regard to functions/benefits/services that can be related to any of the UGI objectives. Based on the content exploration and in-depth analysis all relevant articles were coded, according to the UGI objectives and functions. In addition we used 'backward snowballing' and 'forward snowballing' (Hagen-Zanker and Mallett, 2013) to identify additional research papers to be included in our synthesis.

Finally, we evaluated any evidence found (step 6), using a "fourbox" model, adapted from Moss and Schneider (2000). This model is suitable for evaluating the relative degree of certainty for communication of scientific evidence and has been applied for assessments on different scales, from global, like the IPCC (Mastrandrea et al., 2011) and IPBES (Ferrier et al., 2016) to regional (e.g. Romero-Lankao et al., 2012; Kleemann et al., 2017). Assessment of evidence applies to the principle of credibility, to warrant transparency, quality, rigor and validity of evidence.

We categorized confidence of evidence into four classes – established, limited, indirect, and unverified. Assignment to the categories took place according to findings in scientific literature, thereby distinguishing the number of research items found that support evidence and the interrelation between UPUF and its function in an explicit functional urban context (Fig. 3). Confidence of evidence was considered as 'established' if a minimum of at least three different independent studies confirmed the statement of the function and potentials within the functional urban context. Confidence of evidence was considered as 'limited' if only a limited number of studies (max. of two independent studies) confirmed the statement of the function and potentials within an explicit functional urban context (limited evidence). Furthermore, confidence of evidence was considered as 'indirect evidence', if studies did not consider the functional urban context explicitly but showed evidence in other contexts (for instance in rural contexts), that suggested potential transferability to the functional urban context. If studies showed inconsistent results or if any possible contribution was subject of speculation only, the confidence of evidence was considered as 'unverified evidence'.

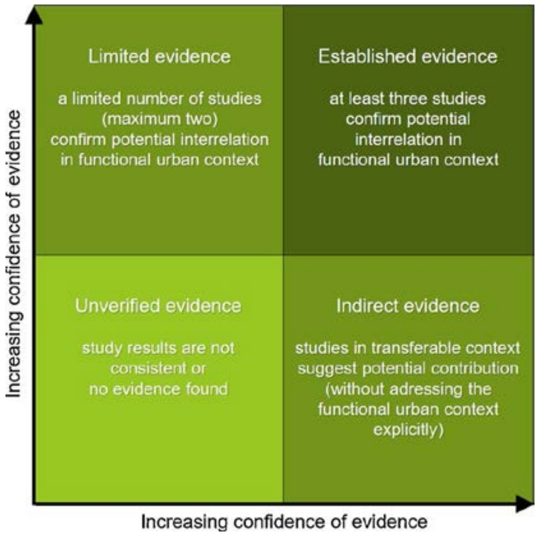

Figure 3. Confidence of evidence was categorized into four classes – established, limited, indirect, and unverified (adapted and modified according to Moss and Schneider, 2000; Mastrandrea et al., 2011; Ferrier et al., 2016).

3. *Results*

3.1. *Policy document analysis*

The analysis of the EUR-Lex database revealed 159 preparatory documents containing key terms of interest in regard to a future integration of UGI into EU level policies during the years 2015–2018, authored by 24 different EU institutions (DGs, Commissions, Councils etc.). However, this analysis indicates that future policies do not considers agriculture in the context of UGI nor to address UPUF. Still, evidence for political awareness exists. A resolution of the European Parliament about CAP and job creation in rural areas from 2016 recognises the relevance of UPUA regarding changing consumption models and of the rural development programme to enhance rural- urban interlinkages (OJ 2018/C 215/34). Furthermore, the European Parliament calls in a resolution from April 2017 "on the Member States to provide incentives for urban farm development and other forms of participatory farming and land-sharing arrangements, taking into account, on the one hand, the limited access to farmland in rural areas and, on the other, the growing interest in urban and peri-urban agriculture" (OJ 2018/C 298/15). A recent report on European cohesion policies shows awareness about Natura 2000 including agro-ecosystems within peri-urban areas and interlinkages with urban benefits, such as the access to green space and other ES (c.f. European Union, 2013) and furthermore emphasized its increasing relevance in the near future for sustainable cities (European Commission, 2017b).

In particular, four current developments were identified as relevant for potential future policy linkages, namely the strategic framework for further deployment of EU-level green and blue infrastructure, the CAP funding period 2021–2027, the LIFE programme 2021–2027, and the post 2020 EU Biodiversity Strategy.

The guidance document on a strategic framework for further deployment of EU-level green and blue infrastructure currently under development fosters an EU-level coherent approach and to enhance effectivity of EU funding (EC DG Env., 2018, Draft 1), in accordance with Action 12 as part of the 'Nature Action Plan 2017-2019' (European Commission, 2017c) and the staff working document that belongs to it (European Commission, 2017d). Essentially, the guidance document links EU-level GI projects to EU policy objectives on mitigation, climate change adaptation, regional development and social cohesion, more sustainable CAP, innovative objectives via nature-based solutions, and to conserve and restore cultural heritage. In functional urban contexts these considerations include functions contributing "to urban regeneration, enhanced quality of life, improved human health, sustainable food production, social cohesion and sustainable economic growth." (EC DG Env., 2018, Draft 1).

While looking at the upcoming funding period 2021–2027, the new CAP Strategic Plans (European Commission, 2018a) reveal that neither the EU GI strategy nor agricultural policy in functional urban contexts will receive particular attention among the '9 CAP objectives' defined (ibid. 11). However, several objectives still offer potentials for indirect benefits from which peri-urban agriculture might profit from funding. This relates to CAP objective f) contribution to the protection of biodiversity, enhancement of ES and preservation of habitats and landscapes, besides CAP objective g) attraction of young farmers and facilitation of business development, and CAP objective d) contribution to climate change mitigation and adaptation. Furthermore, UPUA can be related to changing consumption models to improve job creation by CAP (OJ 2018/C 215/34). Also, the European Parliament asks member states "to provide incentives for urban farm development and other forms of participatory farming and land-sharing arrangements, taking into account, on the one hand, the limited access to farmland in rural areas and, on the other, the growing interest in urban and peri-urban agriculture" (OJ 2018/C 298/15). In regard to the first pillar budget, the proposed flexibility for member states as defined by article 28 "Schemes for the climate and the environment" (eco-schemes), which may help to tailor interventions and measures, was adapted to regional characteristics (European Commission, 2018b:52).

In addition to these considerations, further statements on policy needs were detected that address agriculture in European urban areas as articulated by the European Economic and Social Committee. An exploratory opinion claims the need for infrastructure and investments that facilitate producers' direct sales in urban areas, in order to reorganize food supply chains with the aim of reconnecting producers and consumers. The re-localization of agricultural and food production, is believed to lead to positive social and economic positive impacts, and finally to more sustainable food systems (OJ 2016/C 303/08). Furthermore, it requests 'much stronger efforts' in the agricultural sector to maintain and enhance biodiversity, and points out the role of CAP in this regard. It calls for additional large-scale as well as small-scale measures to implement the GI strategy sufficiently (OJ 2016/C 487/ 03).

The LIFE programme for environment and climate action will receive a budget of 5450 billion euro, according to the proposed multiannual Financial Framework for 2021–2027 (European Commission, 2018a,b,c). This is a significant increase, in comparison to the previous funding periods. While significant changes were found in regard to mainstreaming climate action, no significant changes tackling UPUF are considered yet. Thus, its relevance can be expected to stay comparable to previous periods, primarily supporting conservation and restoration within protected areas and with limited impact on measures in peri- urban areas (c.f. Trinomics, 2015).

Further potential has been identified for EU policies that follow the European post-2020 Biodiversity Strategy. Already at this point in time, studies are being conducted to prepare the development (e.g. Timpte et al., 2018). The midterm review of the EU's Biodiversity Strategy, for example, indicate future potentials of pastoralist approaches in the context of urban planning. This would preserve open spaces and biodiversity, decrease natural risks, and help to develop a coherent blue- green infrastructure also in urban areas while enabling economic activities at the same time (OJ 2018/C 035/01).

To summarise our results from this analysis: Policy integration of UGI development and maintenance addressing UPUF could be assigned to three main European level policy fields, covered by Directorate Generals of the European Commission namely, Environment (DG ENV), Agriculture and Rural Development (DG AGRI), Regional and Urban Policy and Climate Action (DG REGIO). Still, all European related policy instruments support the development of UPUF rather indirectly. This indirect support pertained largely to the development of GI in rural settings, for conservation, restoration and management of semi-natural and natural landscapes. It can be expected that this partially leads to positive effects for UPUF as well.

3.2. Evidence synthesis

Applying the defined search query in the Scopus database returned 7526 research items in total (6869 articles and 657 reviews). With the help of text context analysis using word trees in NVivo and further document examination about 54 literature findings were identified that provide evidence for the four UGI objectives.

Based on the four box-model, evidence assessment has been conducted as summarised in Table 3 and Fig. 4.

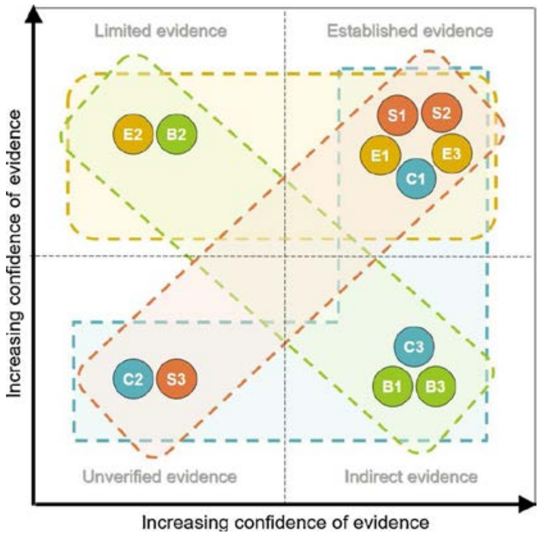

Figure 4. Summary of evidence synthesis, using the four box model to assess confidence of evidence related to potential contribution in an explicit functional urban context (for acronyms of different functions, i.e. E1-E3, B1-3 etc., see the first column in Table 3).

Table 3. Detailed results of evidence synthesis listing identified scientific literature for each the different criteria that have been deductively elaborated from literature (acronyms in first column relates to figure 4).

Criteria function with potential contribution		Confidence of evidence	Literature supporting evidence
UGI objective: promoting green economy			
E1	UPUF bears potentials for energy efficiency and reduction of the urban 'footprint', by more efficient supply chains and shorter distances from producers to markets due to productive farmland at the urban fringe.	Established evidence	Kulak et al. 2013, Benis and Ferrão 2017, Goldstein et al. 2017
E2	UPUF bears potentials for climate change mitigation, i.e. carbon storage due to appropriate management practices for urban food production.	Limited evidence	Poeplau et al., 2011; Lorenz and Lal, 2015
E3	UPUF bears potentials for sustainable economic growth as consumer-oriented diversification strategy and adaptation taking advantage by the 'urban market', offering farmers new income situations	Established evidence	Zasada, 2011; Pölling et al., 2017; Pölling and Mergenthaler, 2017; Henke and Vanni, 2017; Wästfelt and Zhang, 2016
UGI objective: increasing social cohesion			
S1	UPUF bears potentials for sustainable social development and to connect rurality and urbanity due constructing social activities and networks to stimulate active involvement and as a node to strengthen relationships and between farmers and citizens	Established evidence	Callway 2013, Pearson et al., 2011; Santo et al. 2016; Kikuchi, 2008; Henke and Vanni, 2017; Dimitri et al., 2016; Pölling, 2016
S2	UPUF bears potentials for place making, community and neighbourhood building, enhance connectivity to local knowledge and identity	Established evidence	Kneafsey, 2010; Vejre et al., 2010; Howley, 2011; Vitiello and Wolf-Powers, 2014; Almeida et al. 2016; Poulsen et al., 2017; van Zanten et al., 2016; Sahraoui et al. 2016
S3	UPUF bears potentials to promote equity and human well- being, due to equity and justice, food security physical and mental recreation and regeneration	Unverified evidence	Brinkley, 2013; Baró et al., 2017; Zasada, 2017
UGI objective: conservation of biodiversity			
B1	UPUF bears potential contributions to biodiversity due to low-intensity farmland management, contributing to natural and cultural diversity.	Indirect evidence	Hector and Bagchi, 2007; Blüthgen et al., 2012; Allan et al., 2015; Bates et al., 2011; Geslin et al., 2013; Ahrné et al. 2009; Schüpbach et al., 2008; Pölling, 2016;
B2	UPUF bears potentials for increased awareness and willingness of farmers to promote biodiversity and natural amenities.	Limited evidence	Vandermeulen et al., 2006; Lange et al., 2013
B3	UPUF bears potential contributions to biodiversity due to complementary measures alongside agricultural productions, such as field margins to enhance permeability for wildlife, promoting dispersal in the urban and peri-urban landscape matrix	Indirect evidence	Kleijn and van Langevelde, 2006; Herzon and Helenius, 2008; Jauker et al., 2009; Nicholls et al., 2001; Bianchi et al., 2006; Olson and Wäckers, 2007; Gagic et al., 2017
UGI objective: adaptation to climate change			
C1	UPUF bears potential contributions for urban temperature regulation, functioning as fresh and cold-air production areas in functional spatial relation to settlement structures.	Established evidence	Yilmaz et. al., 2015; Aslan and Koc San, 2016; Lee et al., 2015; Bartesaghi Koc, 2018
C2	UPUF bears potentials contributions for urban temperature regulation due to ventilation, such as agricultural grassland meadows designed as wind channel.	Unverified evidence	Zölch et al., 2019
C3	UPUF bears potentials contributions to reduce storm water runoff, functioning as bio-retention system, due to stormwater harvesting for irrigation or increased water permeability by grassland structure, enhanced infiltration and evapotranspiration.	Indirect evidence	Liebmann et al., 2011; Barbedo et al., 2014;Kong et al., 2014; Poli, 2017; Rahman et al., 2019

4. *Discussion and conclusion*

Although the EU GI strategy clearly defines the aim to promote GI in the main policy areas, the analysis reveals, that some limitations remain when looking at UPUF. On the other hand, scientific evidence suggests that UPUA can contribute to human well-being in functional urban areas and help to tackle major challenges of urbanization, such as biodiversity, climate change, social cohesion and green economy. With respect to both aspects this work leads to a number of reflections. In accordance to the research questions we will first discuss how the current development of future European level policies promotes UPUF supporting UGI objectives. We will then follow up on how the current scientific research supports evidence-based policymaking, before we will draw some further conclusions that emerge from this work.

4.1. Targeting UPUF on UGI by future policies

Our first reflection will be about the question of how recent steps and considerations at the EU level promote the European GI strategy by EU policies. The analysis of policy documents shows that European policies insufficiently target UPUA on UGI related objectives sufficiently (c.f. Marsden and Jay, 2017) and potential benefits that may be assigned to the functional urban area, such as values for landscape- oriented recreation or urban climate adaptation are hardly considered at all. Although UPUF may benefit indirectly from European funding programs, up to now, no EU level policies specifically target the contribution of UPUF to UGI in future. This is in line to the findings of Piorr et al. (2018), with regard to UPUA.

At this point it may be argued that missing consolidation of the term 'Green Infrastructure' within policies may lead to misinterpretation, because pre-existing policies do not refer to this term but are still considered strategic cornerstones of GI – such as the 'Habitats Directive' and 'Birds Directive', which constitute the European Natura 2000 network as the backbone of a Trans-European GI. On the other hand, policy integration is an explicitly declared objective of the GI strategy. Therefore we conclude, that missing use of the term in preparatory documents can be also interpreted as an incoherence or gap while mainstreaming GI concept in upcoming EU policies such as the CAP 2021–2027 – in particular while looking at agriculture in an explicit functional urban context. Thus, potentialities remain unexploited. However, possibilities for EU policy incentives, such as instruments included in CAP, to promote biodiversity and ES have been discussed comprehensive lately (e.g. Uthes and Matzdorf, 2013; van Zanten et al., 2014; Pe'er et al., 2014; Batáry et al., 2015; Hodge et al., 2015; Sutcliffe et al., 2015; Huttunen and Peltomaa, 2016; Pe'er et al., 2017).

Another reflection addresses the policy fields of relevance while constructing evidence in future. Policy integration of UGI development and maintenance in UPUF needs to be addressed by different European level policy fields of the Directorate Generals of the European Commission. With Environment (DG ENV), Agriculture and Rural Development (DG AGRI), Regional and Urban Policy and Climate Action (DG REGIO) found most closely linked, it seems obvious to focus on these policy fields first. However, we follow the argument of Parkhurst (2017), that next to being addressed by different sectors, it also requires cross-sectoral approaches which challenge horizontal political efforts. If UGI is to be understood as a strategy for sustainable urban development, it consequently needs to tackle multiple interactions and interwoven social, ecological, and economic urban challenges that fall within policy problems considered to be of 'wicked' nature due to their complexity and potential feedback loops (Rittel and Webber, 1973; Head and Xiang, 2016).

Next to horizontal, cross-sectoral governance processes described above, it is equally important to look at vertically dispersed authority between different levels of administration – supranational, national, subnational (c.f. Enderlein et al., 2010; Cairney et al., 2019). European policy is based on an interplay between European Union and National level, whereas EU level policies define overarching aims, objectives, strategies, and funding principles, which are binding or non-binding for the member states. Addressing the functional urban context at a landscape scale and with regard to its implementation, EU level policies need to be linked to policies at regional and local level. The importance to enhance coordination across policy levels – from European and National down to regional and local, municipal and even sub-local – have already been expressed in other land use planning contexts (Muñoz- Rojas et al., 2015; Duckett et al., 2016). Although studies have identified good practice for the GI integration on the regional and local policy level and implementation by spatial planning strategies and plans across Europe (e.g. Hansen et al., 2017; Grădinaru and Hersperger, 2019) there still seems to be a missing link in the implementation of UGI and agriculture in peri-urban areas (EC DG Env., 2017). One crucial factor for better GI implementation appears to be the adjustability of European policies to local and regional needs (Schmidt and Hauck, 2018). In this regard the proposed flexibility of future CAP for member states as defined by article 28 "Schemes for the climate and the environment" seems to be promising. While the opportunity to remunerate farmers for tangible societal benefits (DNR, 2019) is seen as more productive than the current practice of 'greening', new challenges have become apparent (Brunner and Bradley, 2018; Marsden and Ray, 2018). On the one hand, a remuneration of farmers helps the tailoring of interventions and measures to regional characteristics, on the other hand this challenges national authorities to provide an appropriate evidence base for policy and planning to fulfil this task effectively (Erjavec, 2018). Hence' good' or 'appropriate evidence for policy' is not just of high scientific quality but addresses key policy concerns at hand, and is applicable to the local context (Parkhurst and Abeysinghe, 2016; Parkhurst, 2017). This needs to be considered while constructing evidence to support policymaking for the development of future policies.

4.2. Benefits of UPUF contributing to UGI policy objectives

This brings us to the next reflection, on how the evidence synthesis reveals the contribution of UPUF to UGI objectives as summarised in Table 3. There is scientific evidence that agriculture contributes in various ways to the quality of life and human wellbeing in functional urban areas. The results of our evidence synthesis provide some deeper insight and a better understanding about linkages between UPUF and their contribution to UGI objectives. Nevertheless, this evidence synthesis is limited due to the first step of our literature analysis conducted in Scopus. It can be further extended by integrating scientific literature earlier than 2000 or literature by using additional keywords that is not strictly limiting to urban context. Hence, this evidence synthesis needs to be seen as a very first draft and we encourage the scientific community to extend it by additional research findings and by addressing the research gaps as pointed out in the following.

A number of studies have been identified for established evidence that interlink UPUF with the green economy concept with regards to supply chains efficiency, enhanced carbon footprint and sustainable economic growth (c.f. Zimmermann and Simpson, 2013). This offers powerful arguments to promote UPUF better in future policies, while maintaining and promoting productive farmland at the urban fringe. However, it is important to look beyond the sheer distance of food production and its implications on transport, logistics and infrastructure (the "food miles"-debate), and instead to broaden the context to further environmental and social factors besides energy efficiency (Born and Purcell, 2006). These include the stimulation of sustainable production and consumption patterns, mixed-ownership-economy, and inclusive green local economy, like information sharing and active involvement (Callway, 2013). Therefore, it is also important to see this together in the context of further evidence that suggest UPUF as an 'arena' promoting sustainable metropolitan agri-food systems with benefits for both the consumer and the producer as well as other landscape services i.e. urban benefits, as mentioned in the following two paragraphs.

With regard to social cohesion, the evidence base seems to be more ambivalent. Several studies indicate sustainable social development through the construction of social activities and networks and due to strengthen relationships and between farmers and citizens. A number of studies further indicate the value for recreation opportunities and human regeneration of the UPUF at the urban fringe for city dwellers. However, it needs to be considered that appreciation is also depending on socio-cultural background (Surová et al., 2016; Janečková Molnárová et al., 2017; Bishop, 2019; Hoyle et al., 2019; Serrano- Montes et al., 2019). There seem to be research gaps with regard to physical and mental health effects (e.g. Kaplan, 1973; Lovell, 2010), self-sufficiency (e.g. Colasanti, 2010; Grewal et al., 2012) and production value (e.g. Christensen, 2007) as studies are primarily addressing alternative food systems related to small scale gardening activities as one form of UPUA. Furthermore, studies have shown that UPUA may even perpetuate inequitable systems or even reinforce existing inequalities (Reynolds, 2015; Glennie and Alkon, 2018; Siegner et al., 2018).

Missing evidence is also related to linkages, effects, potentials and constraints, of the UPUF to biodiversity within the functional urban context. There is a long history of studies in urban ecology addressing the urban-rural gradient (McKinney, 2002; McDonnell et al., 2008; Kowarik, 2011) and a common understanding that traditional agricultural management sustained biodiversity in multifunctional landscapes preserve natural and cultural diversity and their socio-cultural values across Europe (Oppermann et al., 2012). Although there is evidence given that species rich farmlands in the surrounding may also positively affect the inner urban biodiversity, in other parts the question remains if agriculture in urban-rural systems brings an advantage to biodiversity conservation measures, for example by linking UPUF management and the production of high-quality food products with visions of aesthetic beauty, visual amenities and cultural heritage. Interesting in this regard is, whether the urban context can support such business models - i.e. management systems - due to an increased awareness among citizens and urban dwellers as informed consumers leading to an increased demand.

In regard to climate change adaptation and its interlinkages between the UPUF and urban build up areas, the evidence base again is ambivalent, but reveals research gaps that need to be addressed in future. Established classification systems on climatopes (Scherer et al., 1999) or local climate zones (Stewart and Oke, 2012), widely used for urban climate mapping assign agricultural land uses, such as meadows, arable land and open fields with or without scattered trees, are found relevant in the context of creating areas for fresh- and cold air production (c.f. Ren et al., 2011). Modelling approaches that analyse the cooling effects of vegetation and wind channel taking into account the spatial distribution and structure of UPUF adjacent to urban settlements are still rare. However, they would provide valuable knowledge for planning climate resilient cities as well as for integrating UPUF.

In sum, UPUF bears potentials to promote economic, social, and environmental benefits, while strengthening mutual relationships not only to support vital farming businesses, offering opportunities for education and information and to support farmland appreciation on the consumer side. While this reveals synergies, this may be also challenging to construct evidence in accordance to the relevant EU level policies identified. However, the consideration of multiple perspectives covered by this evidence synthesis help to legitimate the promotion of UFUP by policies addressing GI as different interests, concerns are considered from multiple perspectives. Furthermore, it becomes clear, that the high number of evidence identified and the assessment conducted supports transparency with regard to the different UGI objective, thus supporting credibility.

4.3. Lessons learned for informed policymaking

Overall it has to be acknowledged, that various European level research policies and programs stimulate valuable impulses, knowledge creation and a better understanding of rural-urban linkages such as the European Commission's sixth framework program (e.g. Piorr et al., 2011), COST action – European Cooperation in Science and Technology (e.g. Lohrberg et al., 2016), the seventh framework program (e.g. van Dijk et al., 2018; Pauleit et al., 2019) or recently by Horizon2020 with emphasis on GI and nature based solutions. To comprehensively tackle UGI together with UPUF, it is important to realize limitations of scientific evidence where policymaking is rather a collective solution strategy of our society interacting with many other factors. The question remains, what steps can be derived to move forward based on our analysis.

This study clearly shows that UPUF have a potential for UGI development, by addressing its multifunctionality, supporting a variety of ecosystem services in peri-urban landscapes, while unfolding synergies between different functions. We think that if UPUF and urban development were brought together their interaction would stimulate sustainable development in either direction. As suggested by this evidence synthesis, UPUF promotes ecological, environmental, social and economic sustainability of cities (c.f. Azunre et al., 2019). The functional urban area can function as an innovation hub for new forms of agriculture, to supply urban demands on food and other products, services and benefits, contributing to sustainability transitions (e.g. Ernstson et al., 2010; Nevens et al., 2013; Loorbach and Shiroyama, 2016). Interlinking agriculture with the functional urban context may also give new impulses to the political debate, for example in regard to climate change mitigation and adaptation. Here the debate in the agricultural sector is currently focusing on strategies and measures to reduce emissions of greenhouse gases, such as by livestock breeding, soil management (grassland conversion, drainage systems, or sustainable fen cultivation), renewable energy production due to biomass, energy efficiency in many different regards stress resistance in crops and management forms (e.g. Challinor et al., 2014; Lipper et al., 2014; Campbell et al., 2016; Paustian et al., 2016; Wollenberg et al., 2016). As illustrated by this work, the functional urban context offers arguments to extend this debate beyond energy efficiency to, for example, an urban 'footprint' as a climate change mitigation strategy. Urban development integrating agriculture offers new ways for cities' climate change mitigation and adaptation strategies, such as planned agricultural wind channels maintained by low intensity grassland meadows in combination with protection or even renaturation of wetlands – reducing greenhouse gases in urban soils and cooling urban heat islands, improving human comfort and health (e.g. Wilby, 2007; Rosenzweig et al., 2018).

As such it is important not to focus on economic principals only, although good evidence supports the economic dimension as a main factor as pointed out by our literature analysis. However, it can be argued that the higher evidence base for economic benefits might be biased by a stronger focus in research on economic issues. Therefore, we suggest to put further emphasis on the inclusion of ecological, environmental and social factors as well. We also emphasise the interactions between different functions as benefits, since there are interlinkages, synergies and trade-offs (Bennett et al., 2009).

The evidence provided in this study sheds some light on the concept of multifunctionality and the management of trade-offs in the rural urban nexus i.e. to promote synergies between different functions and benefits for both agriculture and cities. Consequently, EU policies should tailor incentives across sectors while looking at the landscape scale to enhance effectiveness. The financial basis for this change in direction would be best secured by a CAP programme that provides for agri-environmental measures beyond rural areas covering as much surface as possible and more strongly targets peri-urban regions with higher population density (c.f. Lohrberg et al., 2016). Moreover, policy implementation requires a polycentric and multi-level approach, where European politics can set some basic policy parameters (objectives, types of intervention and basic requirements) while national administrations have the flexibility to adapt to local needs.

4.4. Final conclusions

To conclude, this study confirms our prior impression that UPUF are not sufficiently addressed in the concept of UGI by current considerations on future policies. Although, the awareness for a deep policy integration of GI across sectors at the EU level is high, they do not promote the UPUF as part of UGI. On the other hand, based on a documentary analysis and further evidence analysis, it has been shown that UPUF contributes in various ways to policy objectives, contributing to quality of life and human well-being in functional urban areas. Besides evidence given gaps could be structured and highlighted, thereby putting forward the most obvious gaps and research questions. Furthermore, the structured approach used to evaluate the level of evidence reveals the potentials of existing frameworks and regulations to improve the consideration of UPUF in urban spatial planning. Reciprocal consideration between EU level policies and scientific evidence give first hints how evidence needs to be further constructed to promote a parallel approach of horizontal as well as vertical policy integration, especially in relation to the CAP as the most practice-oriented framework for an implementation of agriculture-based developments. Furthermore, we propose that policymaking should use the increasing awareness in urban societies for problems linked to climate and biodiversity protection as well as for general problems of health and well-being related to urbanisation. It appears that there is a lack to look beyond policy traditions surpassing urban–rural dichotomy. This may be hindering while trying to overcome the deep separation between rural agricultural landscapes and urban settlement planning.

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3. DISCUSSION OF RESULTS

The potential contributions of peri-urban farmland to UGI as a strategy to promote sustainable urban development have been addressed from different perspectives. They will now be discussed in the light of the different findings.

The discussion begins with insights that emerge from this work with regard to the development of multifunctional green space networks by peri-urban farmland based on the two GI core principles connectivity and multifunctionality.

In the second step, linkages between peri-urban farmland and the UGI concept will be elaborated to show their suitability for the strategic spatial planning of multifunctional green space networks that address major urban challenges, namely biodiversity conservation, climate change adaptation, green economy development, and social cohesion.

The third part will reflect on how the linkage of peri-urban farmland to UGI planning promotes pathways of transformation towards sustainable urban development.

3.1. CONTRIBUTIONS OF GI CORE PRINCIPLES TO MULTIFUNCTIONAL GREEN SPACE NETWORKS

3.1.1. CONNECTIVITY STEERS – SUPPORTING ECOLOGICAL, ABIOTIC AND SOCIAL PROCESSES

This work offers a number of insights addressing potential contributions of peri-urban farmland to ecological, social and abiotic functions and benefits related to structural and functional connectivity (cf. Merriam, 1984; Baudry and Merriam, 1988 Auffret et al., 2015). As such it extends the literature on urban green space planning from its usual focus on ecological connectivity, such as the movement and interactions of wildlife (e.g., Rudd et al., 2002; Kong et al., 2010) to the understanding that UGI networks address further aspects of ecological connectivity, such as enhanced accessibility for recreation, sustainable mobility due to safe and attractive bicycle paths as well as air ventilation leading to improved air quality and cooling effects in urban heat islands (Ahern, 2007; Hansen et al., 2016).

Based on the results of Article-I, farmland offers significant spatial potentials for the development of a multifunctional network. Although outcomes of this analysis refer to structural connectivity, further insights emerge, synthesized with results of Article-III and Article-IV. With an emphasis on ecological connectivity, the consideration of semi-natural farmland as part of UGI offers the potential to support the inner urban biodiversity. In particular, this is evidenced by pollinators (Bates et al., 2011; Geslin et al., 2013; Ahrné et al., 2009). This finding, interestingly, matches the implementation of the European Pollinators Initiative (European Commission, 2018a). Thus, it addresses a broad public concern about biodiversity and natural systems, perceived as highly relevant for future generations, as shown by public consultation across Europe (European Commission, 2018b). Based on stakeholder opinions in the Malmö study (Article-III), further ecological functions can be supported beyond semi-natural farmland, as demonstrated by complementary measures in highly productive agricultural landscapes that also support connectivity and promote networks for wildlife.

As identified in the evidence synthesis (Article-IV), two modes emerge, how peri-urban farmland promotes connectivity while looking at social processes and functions. First, farmland corridors themselves contribute to alternative mobility such as walking and cycling, for instance, by linking quarters or districts separated by farmland, thus contributing to the recreation networks, which is being considered as one relevant objective to be provided by UGI. Second, farmland offers promising potential near to residences and neighborhoods for physical activity (cf. Saelens et al., 2008; Ward Thomson 2013; Sallis et al., 2016) and wellbeing effects (cf. Tzoulas et al., 2007; Bowler et al., 2010b; Keniger et al., 2013).

Furthermore, this work gathers evidence (Article-IV) about how farmland potentially supports abiotic processes and functions due to connectivity: The general structure of farmland is suitable for ventilation corridors, thus improving the supply of fresh air and reducing air pollution. In addition, due to high evapotranspiration rates, wet grassland farming systems efficiently function as cooling systems for the urban system. However, modeling approaches are needed to better predict these effects, taking into account the spatial pattern of the agricultural landscape and the urban structure, for instance, to design efficient wind channels (cf. Kong et al., 2014; Lee et al., 2015; Bartesaghi Koc, 2018; Zölch et al., 2019). Modeling could fill valuable knowledge gaps, enabling a better consideration of farmland as a regulator of local climate in urban development planning.

In sum, synthesizing results of this work utilizable agricultural land can contribute to GI and enhance connectivity, steering ecological, social and abiotic processes and functions. As a consequence, it can be argued that peri-urban farmland can purposefully complement UGI as an interconnected network, together with parks, forests and other urban green spaces.

3.1.2. MULTIFUNCTIONALITY CONCERNS – MULTIPLE BENEFITS EMERGE FROM HETEROGENEITY

In addition to the vast knowledge existing about multifunctionality concept and agriculture at the farm level (e.g., Van Veenhuizen and Danso, 2007; Pearson et al., 2010; Zasada, 2011; Viljoen and Bohn, 2014; Zeeuw and Drechsel, 2015; Rogus and Dimitri, 2015; Goldstein et al., 2016; Lohrberg et al., 2016) this thesis gives insights about multifunctionality and agriculture in the context of GI as a spatial planning approach with an emphasis on the landscape level (cf. Hansen et al., 2017b).

Results from Article-I and Article-III clearly show that peri-urban farmland offers multiple functions contributing to GI, thus promoting sustainable land use (cf. OECD, 2001; Wiggering et al., 2003). The multifunctionality framework is appropriate to promote synergies between different functions and to deal with trade-offs in the peri-urban landscape (cf. Brandt and Vejre, 2004; Raudsepp-Hearne et. al. 2010; Westerink et al., 2014). The importance of considering and accommodating different values among stakeholders cannot be stressed too much. As shown by the Malmö case study (Article-III), the participatory approach using scenario techniques as adapted from Nassauer and Corry (2004), integrating stakeholder valuation was providing a useful framework for knowledge co-production. This approach helped to co-develop scenarios at a fine-grained scale, and in doing so, helped to consider the complex relationships between different needs, values, their synergies and conflicts and to negotiate strategic objectives, including the identification of priority functions, comprising key functions and additional functions in meaningful bundles suitable for UGI planning. Evidence synthesis (Article-IV) helped to strengthen and refine the different options regarding the interacting functions based on the current stage of scientific knowledge. Hence, this thesis provides a knowledge base for UGI planning that will contribute to a better understanding and increased acceptance by stakeholders, and thus promote integration across sectors and scales which is considered as crucial for effective sustainable planning (Geneletti et. al. 2017).

Another outcome of this work is that its results strengthen confidence in the proposition that meaningful bundles of multiple functions suitable for UGI development are strongly related to landscape heterogeneity and its different site characteristics defining agricultural potentials (cf. Haber, 1971; Benton et al., 2003; Tscharntke et al., 2005), as illustrated by the four strategies for spatial planning in the following section (chapter 3.2) – while some relate to farmland of high productivity others assist on sites of less agricultural productivity. This outcome suggests that the spatial allocation of the different strategies needs to be carefully considered to intertwine multiple functions for UGI planning in peri-urban farmland to avoid conflicts and to promote win-win situations between agriculture and UGI planning (cf. Larsson 2010; Haaland, et al., 2011; Mouysset et al., 2019). The spatial modeling approach, based on complex ecological interrelations of environmental and cultural factors, as applied in Article-I and Article-II might be a suitable approach for landscape character assessment and for the identification of spatial potentials of areas with different functions. This approach includes both the consideration of environmental conditions (given by biophysical data, such as topographical and local climatic factors, soil and water conditions) and historical land use information. The latter is particularly helpful for larger peri-uban regions if more detailed data are not available, such as mapping low-intensity farmland, which is still considered challenging (cf. Wascher et al., 2010; EEA, 2011; Klimek et al., 2014; Lomba et al., 2017).

Accordingly, the emerging result of this work is that successful GI planning taking into account peri-urban farmland, inevitably needs to respond to landscape character. Therefore, multifunctionality needs to be considered in both space and time where functions are allocated to different land units (i.e., spatial segregation), and that these functions interact with each other (cf. Brandt and Vejre, 2004). With this in mind, the GI approach supports looking at multifunctionality beyond the farm level, taking into account multifunctionality at the landscape level, and eventually considering functions and benefits at a territorial scale (cf. Gullino et al., 2018)

3.2. FOUR WAYS FOR STRATEGIC SPATIAL PLANNING OF A MULTIFUNCTIONAL GREEN SPACE NETWORK

As a result of this work, four different spatial planning strategies have emerged that show the ability to link peri-urban farmland with the UGI conception (i.e., to develop a multifunctional green space network). These are the connecting, the productive, the integrated, and the adapted way (figure 9).

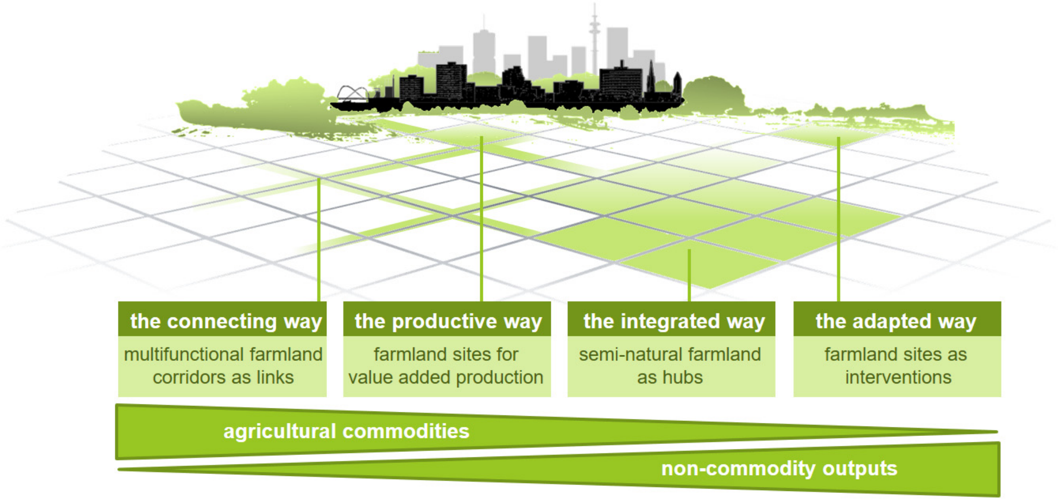

Fig. 9. Schematic illustration of four ways linking farmland with the UGI concept and their relation to agricultural commodities and non-commodity outputs.

These types were initially developed as part of the case study in Malmö (Article-III), by taking into account the valuation and appreciation of functions by different stakeholders. But, they can be refined by incorporating evidence synthesis, reflecting processes and their causal effects of functions and benefits (Article-IV). Finally, they need to be related to landscape heterogeneity, as addressed in Article-I.

These strategies, as presented by this thesis, may be understood as ideal types, representing an abstraction of real, existing individual phenomena that intertwine physical, ecological, social, as well as the economic functions of a multifunctional UGI network. They have been scaled to elements suitable for discussing options for UGI development. Furthermore, they relate to the basic network conception of hubs, links and sites as illustrated in figure 3 (cf. Benedict and McMahon, 2006). Thus, these four strategies have the ability to stimulate discussion about how UGI planning can and should incorporate utilizable agricultural land, especially the agriculturally dominated landscape at the urban fringe and its surroundings.

3.2.1. THE CONNECTING WAY – MULTIFUNCTIONAL FARMLAND CORRIDORS AS LINKS

As a first spatial planning strategy, this work suggests 'multifunctional farmland corridors' as a 'pathway' to develop UGI links within agriculturally dominated green belts or rings at the urban fringe (cf. Timpe et al., 2016). Multifunctional farmland corridors are understood as linear network elements in a highly productive agricultural landscape that do not interfere with on-site productivity (figure 10).

Fig. 10. Illustration of multifunctional farmland corridors with potential key functions and benefits addressing urban challenges.

They significantly contribute to a functional recreational network by offering opportunities for leisure activities (e.g., walking, cycling, riding) and enhancing accessibility to the wider landscape for urban dwellers (cf. Ingersoll, 2013). This option gains high acceptance and appreciation by a number of different stakeholders, including farmers as key actors, as found out in Article-III, due to its potentials for a variety of functions. Several UGI objectives, besides recreation, can be underpinned by established scientific evidence, as shown in Article-IV. These comprise accompanying margin strips that promote dispersal within the landscape matrix and provide small habitat opportunities for wildlife thereby augmenting urban biodiversity. Furthermore, farmland corridors can be beneficial for farmers by contributing to biological pest control and pollination or prevent soil erosion. Consequently, this thesis suggests multifunctional farmland corridors as a striking example of a UGI network element within the agriculturally dominated landscape matrix that coherently and mutually reinforces multiple functions.

Acceptance can be increased if farmland corridors are planned in combination with farm tracks, as shown by the study in Malmö (Article-III). This can be explained in part by the benefits resulting from the functions outlined above but also because it is a complementary off-site function, disconnected from the production cycle and thus not interfering with on-site farming activities (see the next section). Accordingly, this option can also be related to the UGI planning principle of 'green in grey integration' (cf. Hansen et al., 2017). Furthermore, this work suggests making use of 'Eh da'-sites (Deubert et al., 2016). These are existing areas that are often neglected or even permanently unmanaged. They can be found in the wider (agricultural) landscape and include spots and edges of farmland and embankments along tracks. To synergize effects best, development of multifunctional farmland corridors as part of UGI should use infrastructural developments, land consolidation procedures and reparcelling as a 'window of opportunity' or by subsequent integration with the existing farm infrastructure. The involvement of land owners of adjacent properties as well as current track users (farmers, recreational users etc.) is considered to be essential.

3.2.2. THE PRODUCTIVE WAY – SITES FOR VALUE ADDED FARM PRODUCTION

The second spatial planning strategy also relates to sites that are of high productivity. In comparison to the previous type, the productive way offers an opportunity to combine UGI development with the agricultural production cycle on-site that benefits directly from the site productivity. It aims to benefit from the fertility of the sites for food production with the inclusion of further social functions, such as recreation, regeneration, and education, into agricultural production, and which offers new farming models and relationships between consumer and producer (figure 11).

As part of Article-III, several ideas have been identified, such as rent-a-field farms or self-picking farms (e.g., fruit, vegetables, flowers) that enable an 'on-field' experience for citizens in their spare time or at the weekend. This outcome is in line with urban gardening and urban agriculture activities (e.g., Heimlich and Barnard 1997;

Lovell 2010; Pearson et al., 2010; Aerts et al., 2016; Lohrberg et al., 2016) but relates them to UGI in the wider agricultural landscape more explicitly. Furthermore, Article-IV gathers established evidence that supports the idea that UGI development does not need to lead to the exclusion of economic benefit for agricultural businesses, but may even promote sustainable economic growth in the agricultural sector. Accordingly, 'the productive way' suggested by this work offers opportunities for alternative business models and new income situations. In addition, it contributes to the efficiency of supply chains, constructs social activities and networks, stimulating active involvement and may function as a node to strengthen relationships between citizens and farmers. Consequently, this work clearly suggests that the consideration of 'productive farmland' as a spatial planning strategy for UGI has the potential to support the Green Economy in several ways, promoting transition from conventional farming to alternative models (cf. Paul and McKenzie, 2013).

Fig. 11. Illustration of productive farmland with potential key functions and benefits addressing urban challenges.

In order to synergize potentials for value-added farm production for UGI integration, this work suggests selecting sites in areas that are fully accessible to citizens, ideally close to residential areas and embedded in recreational networks (see the previous section). However, this option may also be promising for single sites that are suitable for food production but are physically isolated from other UGI elements and even those newly introduced into non-urbanized areas within settlement agglomerations (cf. La Greca et al., 2011). Such sites can complement UGI and extend the functions of other urban green spaces, contributing to the livability of the urban environment. Overall, this option illustrates potentials for collaboration and cooperation between farmers and urban development authorities, presenting a positive example for a cross-sectoral UGI planning.

3.2.3. THE INTEGRATED WAY – SEMI-NATURAL FARMLAND AS HUBS

In contrast to the previous two, the third spatial planning strategy is more related to sites of low agricultural productivity. As supported by the quantitative analysis in Article-I, there may be significant spatial potential for low-intensity farmland within the peri-urban landscape. The integrated strategy reflects region-specific management practices that are constrained by prevailing environmental conditions (soil, climate, topography) and their geophysical constraints (cf. Beaufoy et al., 1994). Accordingly, management can be very different, with or without livestock or mixed. The farmland may vary in character, ranging from grassland systems, such as meadows and pastures, to agroforestry and cropping systems, like pastoral woodland, orchards, olive groves and other arable systems (cf. Oppermann et al., 2012). Structured as a mosaic of cultivation and semi-natural vegetation, they often have integrated historical features, such as hedgerows, stone walls, ponds, or trees (ibid.). As discussed with the different stakeholders (Article-III) and supported by evidence (Article-IV), semi-natural farmland provides a number of positive externalities from agriculture, i.e., integrated amenities, such as ecological and social-cultural functions and values contributing to the quality of the urban environment (figure 12). If certain EU agri-environmental indicators apply, semi-natural farmland can be defined as having "high nature value" (HNV) (Paracchini and Capitani, 2012).

provides various ecological and social-cultural functions and values; contributing to the quality of the urban environment, advocate for ecosystem stewardship and new collaboration models in peri-urban landscapes

Fig. 12. Illustration of semi-natural farmland with potential key functions and benefits addressing urban challenges.

Accordingly, this thesis suggests semi-natural farmland as hubs, serving as building blocks for the UGI network, suitable for conservation of biodiversity and the maintenance of natural ecological processes (cf. Benedict and McMahon, 2006). If protected as areas under 'Habitats Directive' (Council Directive 92/43/EEC) or 'Birds Directive' (Directive 2009/147/EC), they may, in addition, interlink different scales, the regional UGI with the Natura 2000 network as the backbone of trans-european green infrastructure (cf. European Commission, 2019).

UGI planning ought to support the management of semi-natural farmland in the peri-urban landscape, to prevent areas from agricultural abandonment or to avoid intensification. However, this does not necessarily need to lead to museumization. Rather it advocates semi-natural farmland as a vital part of the urban, that promotes ecosystem stewardship and collaboration (cf. Bieling and Plieninger, 2017; Lomba et al., 2019), generating and catalyzing new pathways for innovative ecosystem management leading to more sustainable and balanced land use and urban growth. As a consequence, this thesis shows that UGI, as an integrated cross-sectoral spatial planning approach, also offers opportunities to contribute to the development of future-oriented pathways to the conservation semi-natural farmland.

3.2.4. THE ADAPTED WAY – SITES FOR FARMING AS INTERVENTIONS

The fourth spatial planning strategy sheds light on the introduction of adapted farm management at sites that have not been under agricultural cultivation previously to promote non-commodity output values to introduce and/or support processes and functions with non-commodity, as alternative management contributing to UGI (figure 13). Grazing management offers opportunities for active ecological rehabilitation and restoration, respectively, for the reparation of ecosystem processes, functions and services and to support the re-establishment of species compositions and community structure (cf. SER, 2004; Holl and Aide 2011). Article-III discussed the potentials of social-cultural services farms for nature experience and education for urban dwellers, school classes, etc. especially when accessible and integrated with a recreation network.

Fig 13. Illustration of adapted farmland with potential key functions and benefits addressing urban challenges.

Furthermore, inner-urban adapted farmland management, such as grazing can be an alternative for urban greenery as part of UGI. Farmland contributes to inner-urban stormwater retention sites, supplementing green river banks and inner-city fields as ventilation corridors (Article-IV). Although it is known that the presence of grazing livestock adds value to the rural experience for the urban public both aesthetically and recreationally (Zanten et al., 2014; Serrano-Montes et al., 2019), this also applies to the peri-urban agricultural landscape and its values for the urban public (e.g., Vejre et al., 2010; Ives and Kendal, 2013; Sahraoui et al., 2016). This thesis recommends further research to complement the knowledge about potentials and conflicts of grazing management of inner-urban green spaces. Greater insight into the perception of inner-urban farming activities, such as grazing, would help to better understand supporting and hindering mechanisms involved in the successful implementation of such interventions.

In sum, as an outcome of this research, adapted farming may be understood as an intervention to complement or further develop UGI by providing additional functions. Adapted farming presents new opportunities for cooperation with farmers and to develop new business models for UGI maintenance. Nevertheless, the study has also shown that agricultural production is of subordinate relevance at such sites. If farming management is supposed to support functions and provide benefits to the urban people, strong incentives are needed to involve farmers in such interventions (Article-III).

3.3. FARMLAND AND UGI – AN ARENA FOR SUSTAINABILITY TRANSITIONS?

It is believed that due to the long development history of 'mature' cities and to their existing infrastructure, the resulting path dependencies are difficult to change (WBGU, 2016). Nevertheless, urban agglomerations are considered to provide a fertile medium for creativity that can promote the innovation of transformation pathways (ibid.) towards sustainability (e.g., Ernstson et al., 2010; Nevens et al., 2013; Loorbach and Shiroyama, 2016). This final reflection sheds light on the outcomes of this thesis, suggesting that peri-urban farmland linked with UGI planning can support such transformative processes.

In particular, the inherent principle of multifunctionality – as discussed before (see chapter 3.1.2) and as illustrated by the four ways above (see chapter 3.2) – largely contributes to the generation of co-benefits that are considered crucial to trigger transformative processes (WBGU, 2011; 2016). Co-benefits generate shared motivations, which motivate collaborative dynamics (Emerson et al., 2012). As a self-reinforcing cycle of mutual trust and understanding, this legitimizes and stimulates ongoing collaboration, sustaining principled engagement, and vice versa (ibid.). This ongoing collaboration supports future processes of problem-solving and the unfolding creativity reveals new pathways, thus, promoting transformational and systemic change. Although the relationship between collaborative approaches and the improvement of environmental outcomes is difficult to evaluate and rarely shows clear causal relationships (cf. Koontz and Thomas, 2006; Reed, 2008; Scott, 2015; Bodin, 2017), collaborative approaches with a multifunctional landscape perspective do seem to enhance sustainable management of land use and natural resources (Sayer et al., 2013; Cockborn, 2018) and to reduce trade-offs (Cavender Bares et al., 2015), as demonstrated by several recent examples (e.g., Carlson et al. 2017; Raatikainen, 2018; Hossu et al., 2019).

The idea that farmland and UGI may function as a collaboration arena for sustainable development can be further discussed by reflecting on the participatory approach (Article-III) in the light of the four principles for co-knowledge production in sustainability research as proposed by Norström et al. (2020). These principle suggest that processes should be context-based, pluralistic, interactive, and goal-oriented. They are considered as essentials for high-quality knowledge co-production promoting sustainability and can be related as follows. The integration of farmland in the UGI planning process (1) supports the development of context-specific solutions, by taking needs and values (including economic) of the various actors of the region into account; (2) offers opportunities for pluralistic collaboration of researchers and local actors from different sectors to generate knowledge, and (3) offers opportunities for interactive processes among the different stakeholders involved. Furthermore, (4) the overarching goal of the development of UGI, with its different benefits that can be shared among participants, clearly benefits from goal-oriented and problem-focused approaches for knowledge creation.

The results of this thesis indicate that linking peri-urban farmland with the UGI concept is a promising field of action that can lead to the development of new pathways for urban transformation towards sustainable urban development. The discussion presented here contributes to a better understanding and contextualization of farmland and its potentials as part of UGI. Consequently, this discussion concludes by advocating the multiple benefits of farmland and fosters an appreciation of the need for its maintenance as a vital part of the city. Finally, the thesis asserts that sustainable pathways will evolve that deal with land use competition and facilitate synergies that can maintain farmland and lead to a rethinking of the urban-rural divide.

4. CONCLUSION AND FUTURE PERSPECTIVES

Based on the discussions of the previous chapter this chapter draws final conclusions for peri-urban farmland in UGI planning to promote transformation towards sustainable development and outlines future research needs, based on a reflection of the limitations of this research.

4.1. CONTRIBUTIONS OF THE STUDY

In summary, this dissertation thesis on peri-urban farmland and urban green infrastructure is based on three aims:

(1) to explore the contributions of peri-urban farmland to multifunctional green space networks based on the two GI core principles connectivity and multifunctionality,

(2) to identify linkages between peri-urban farmland and UGI to develop a strategic planned multifunctional network, and

(3) to synthesize the theoretical and empirical findings from the applied approaches to identify pathways of transformation towards sustainable urban development.

This thesis contributes to the conceptual understanding of UGI as a strategic spatial planning approach that incorporates both inner-urban utilizable agricultural land and the agriculturally dominated landscape at the urban fringe and its surroundings. Several insights emerge with regard to the two GI core principles connectivity and multifunctionality. One striking outcome to emerge is that peri-urban farmland can contribute to GI and enhance connectivity, steering ecological, social and abiotic processes and functions. Hence, this work concludes that peri-urban farmland can purposefully complement UGI as an interconnected network, together with parks, forests and other urban green spaces. As another outcome, this work has strengthened confidence that meaningful bundles of multiple functions suitable for UGI development are strongly related to landscape heterogeneity and its different site characteristics that define agricultural potentials and constraints. As illustrated by the different strategies proposed, some meaningful bundles relate to farmland of high agricultural productivity while others assist sites of less agricultural productivity. Hence, it can be concluded that spatial allocation of the different multifunctionality planning strategies must be carefully considered to avoid conflicts and to promote win-win situations between agriculture and UGI planning.

This thesis furthermore introduces four different strategies for spatial planning of the contribution of peri-urban farmland to UGI as a strategically planned multifunctional network: (a) the connecting way, with multifunctional farmland corridors as linear network elements, functioning as links of the network, (b) the productive way, as farmland sites that combine agricultural production with a number of social functions and benefits to complement the network, (c) the integrated way, where, in particular, semi-natural farmland is maintained and developed as hubs, suitable for conservation of biodiversity, to maintain natural ecological processes, and to contribute to the quality of the urban environment, and (d) the adapted way, which purposefully uses farming as an intervention on formerly non-agricultural sites to introduce and/or support processes and functions with non-commodity, as an alternative management form. These strategies can be used as recommendations to stimulate UGI planning for incorporating inner-urban utilizable agricultural land and the agriculturally dominated landscape at the urban fringe and its surroundings. However, these findings need to be carefully applied and might need to be adapted to individual situations. More importantly, they need to be negotiated with the stakeholders in each region, because this work has shown that acceptance and successful implementation strongly depends on this. However, these strategies do offer promising starting points, because this work has proven general acceptance by different stakeholders including farmers as key actors.

Besides conclusions with regard to UGI, additional ones can be drawn about UPUA. This has been recently intensively discussed in the academic literature. First, the thesis extends the knowledge of UPUA and multifunctionality that usually focused at the farm level. As such, the conceptual linkage between peri-urban farmland and UGI translates the benefits and social, economic and environmental functions between the spatial scales, from the farm level to the landscape level. Second, although UPUA has been discussed in the UGI context, research tended to focus on small-scale activities. The linkage of peri-urban farmland with the UGI concept highlights that the wider utilizable agricultural landscape can contribute to an interconnected network of multifunctional green spaces to provide multiple benefits to the urban system.

As such, the results of this work widen the current debate about UGI planning that often excludes utilizable agricultural land. Furthermore, they expand knowledge about the multifunctionality of UPUA by providing a detailed picture of UGI aims and objectives. Hence, this thesis offers knowledge about how the UGI concept can link urban and agricultural systems in the peri-urban to successfully address urban challenges such as biodiversity conservation, climate change adaptation, green economy development, and social cohesion.

Finally, this thesis sheds light on the opportunities that arise from the linkage of peri-urban farmland and the UGI conception to support transformation towards sustainable urban development. In particular, the inherent GI principle of multifunctionality endorses the idea of co-benefits that are considered crucial to trigger transformative processes. This is, in addition, further supported by reflecting on the participatory approach of this work in the light of the four principles for co-knowledge production in sustainability research which leads to the conclusion that the linkages support processes that are context-based, pluralistic, interactive and goal-oriented. Thus, it can be concluded that the linkage of peri-urban farmland with the UGI concept is a promising action field for the development of new pathways for urban transformation towards sustainable urban development.

4.2. PERSPECTIVES FOR FURTHER RESEARCH

Despite the outcomes of this thesis, limitations remain to be acknowledged.

First, the present study has only investigated the two core principles of GI, connectivity and multifunctionality. There are several other principles considered important for successful UGI planning, such as the integration and coordination of green with grey infrastructure, multiscale planning, as well as the design of strategic, cooperative and socially inclusive planning processes. These all need to be looked at more specifically. Further research may help to better understand overlaps and interrelations between the different principles for better integration of peri-urban farmland in UGI planning.

Second, there are still knowledge gaps with regard to some important regulating functions to be tackled by UGI. These include, in particular, local climate regulation to support climate change adaptation as one of the main objectives assigned to UGI planning. This work gathers evidence about how farmland potentially supports cooling processes due to their general structure suitable for ventilation corridors and evapotranspiration rates of wet grassland farming systems. Still, it is important to better understand effects of the spatial pattern of the agricultural landscape and the urban structure, for instance, to design efficient wind channels. As pointed out in this thesis, modeling approaches can help to better predict these effects and to support planning that considers farmland for urban climate regulation in urban development planning. In addition, although this work illustrates how the algorithmic landscape approach can contribute to better GI planning by processing ecological information purposefully for communication with stakeholders with limited specialist ecological knowledge, it became clear that more research effort is needed to strengthen ties between geographic information systems science and design to make this approach more applicable.

Besides quantitative biophysical valuations, more sociocultural research is needed. Although this work integrates a participatory research approach to qualitatively evaluate functions and benefits based on stakeholder opinion, more research with regard to the sociocultural valuation of ecosystem services provided by farmland in an explicit peri-urban context is needed. This would help to understand people's attitudes and perceptions better and identify relevant factors for taking co-benefits into account, relevant to the motivation of collaboration and the support of transformational and systemic change towards sustainable urban development. This in particular includes the involvement of farmers as key actors to identify factors for successful partnerships between planning and farming.

The final remark tackles the most significant limitation of this work. Agriculture in Europe strongly depends on European policy frameworks, and urban policymaking at the local level reflects this limitation. Although this work tackles some aspects of policy integration at the European level, more research on this topic is needed. Besides identifying opportunities for supporting policymaking at the EU level, it is also important to identify mechanisms that support policy integration at the local level that are necessary to support the agricultural sector effectively during transformation processes.

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AUTHOR DECLARATION

I hereby declare that I completed the doctoral thesis independently based on the stated resources and aids. I have not applied for a doctoral degree elsewhere and do not have a corresponding doctoral degree. I have not submitted the doctoral thesis, or parts of it, to another academic institution and the thesis has not been accepted or rejected. I declare that I have acknowledged the Doctoral Degree Regulations which underlie the procedure of the Faculty of Science of the University of Potsdam, as amended on 18th September 2013.

Hiermit erkläre ich, die Dissertation selbstständig und nur unter Verwendung der angegebenen Hilfen und Hilfsmittel angefertigt zu haben. Ich erkläre, dass ich die Dissertation oder Teile davon nicht bereits bei einer anderen wissenschaftlichen Einrichtung eingereicht habe und dass sie dort weder angenommen noch abgelehnt wurde. Ich erkläre die Kenntnisnahme der dem Verfahren zugrundeliegenden Promotionsordnung der Mathematisch-Naturwissenschaftlichen Fakultät der Universität Potsdam vom 18. September 2013.

23 March 2020, Werner Rolf