Productive green infrastructure for optimising the urban metabolism the case of Da Nang, Vietnam

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ABSTRACT

The thesis reflects current discourses surrounding human-induced planetary alterations in the Anthropocene that have led to problematic changes in the biosphere. Resource utilisation and food systems are particular drivers of these alterations. Over the past 150 years, the metabolism of cities has continuously expanded into the so-called 'global hinterland'. As the biosphere's regenerative capacities have gradually become exhausted, the interdependency of urban and natural systems becomes increasingly evident again. Emerging *urban metabolism* approaches aim at deciphering urban-natural interrelations by viewing cities as ecosystems of the 'technosphere' that can be optimised by mimicking circular cycling processes in natural ecosystems.

This work focusses on the *urban food system* and *green infrastructure planning* as well as further develops the conceptual approach of *productive green infrastructure* (PGI). PGI aims to address the challenge of assessing the spatial extent of dispersed and informal practices of urban agriculture and its integration into a strategically planned green infrastructure network.

The PGI approach is exemplified through a case study of Da Nang, a rapidly growing city in Vietnam. Da Nang has a rich culture of urban agriculture that has not been subject to urban planning. Through an interlinked process of mapping, aerial picture interpretation, and processing of existing land use data, characteristic typologies of urban agriculture are identified and quantified. The relation between the typologies and the urban metabolism is conceptualised and substantiated with data. The research project 'Rapid Planning' made it possible to integrate the typologies into a simulation model of Da Nang's urban metabolism and to simulate different development scenarios in a collaborative process. One scenario showed, that despite a growing population, the supply of horticultural produce from the region could be stabilised by preserving some of the grown structures of urban agriculture, facilitating their integration into urban extension areas, and gradually shifting from staple crops to vegetables and fruits on remaining agricultural land. Based on the scenario, the approach of green infrastructure is used to draft a spatial framework for a city-region-wide network of green spaces, which marks the turning point of when single elements of urban agriculture become a PGI. Potential links to the existing planning goals, framework and procedures are also reflected.

PGI combines the agenda of green infrastructure and food system planning. It can contribute to make use of urban resources, rendering material flows more sustainable and increasing food security by expanding the choices for healthy and sustainable diets. PGI broadens the search space for developing multifunctional and connected green infrastructure, which is urgently needed for the well-being of urban residents and to buffer the effects of climate change.

1 INTRODUCTION AND RESEARCH OBJECTIVE

1.1 Introduction

Reciprocal dynamics between a growing human population, global urbanisation, and the dominance of neoliberal capitalism are significant drivers of alterations to the Earth's systems, and these changes have resulted in the 'Anthropocene' (Crutzen, 2002) – an era in which humankind is the most influential factor on Earth (Brenner and Schmid, 2014; Steffen et al., 2015). Expansion of urban areas worldwide and the way resources are consumed produce negative effects on the biosphere, which in turn affects the biosphere's capacity to provide resources and regulatory functioning (Cardinale et al., 2012; IPBES, 2019). Moreover, the loss of agricultural land is increasingly impacting the accessibility of food and thus food security worldwide (Bren d'Amour et al., 2016).

This study assumes that *green infrastructure* is indispensable to ensuring the well-being and health of human and nonhuman urban residents (Beatley and Newman, 2013; European Commission, 2013a). The planning concept highlights the need for connectivity between natural and urban systems and strives to identify, maintain, develop, and qualify networks of multifunctional green spaces (European Commission, 2013a; Hansen et al., 2018). The agenda is mostly dedicated to ensuring liveability for citizens and increasing biodiversity by developing and connecting habitats. Like green infrastructure, the *urban food system* planning approach is gaining awareness in urban planning ever since the sphere of food was identified as a 'stranger to the planning system' (Pothukuchi and Kaufman, 2000). The urban food system approach focusses more strongly than green infrastructure on the metabolism of food and related infrastructures (waste, water energy). Disruptions in the food supply in the Global South as well as a widespread rapid increase in diet-related health risks have led to increased attention toward the strategic role of cities in developing sustainable food systems and promoting healthy diets (Milan Urban Food Policy Pact, 2015).

The megacity research project 'Urban Agriculture as an Integrative Factor of Climate-Optimised Urban Development, Casablanca / Morocco*'* (2008-2013) funded by the German Federal Ministry for Education and Research (BMBF), combined both green infrastructure for spatial and strategic planning of manifold green space networks and urban food system planning. This project was the first to introduce the term '*productive green infrastructure*' (Giseke et al., 2015c). Research addressing the synergies between green infrastructure and urban food systems have gained traction in recent years, but still require consolidation and integration into planning practice.

In this thesis, productive green infrastructure (PGI) is understood as a further development of the current green infrastructure concept. This thesis focusses on areas of urban agriculture and, in addition to the spatial layout, also highlights associated material flows and its role in the urban metabolism.

Urban agriculture is generally characterised by a dispersed spatial structure and informal practices. It is not systematically considered in practices of urban planning nor in agricultural administration, and it therefore represents a blind spot in planning (see 1.2). The aim of this work is to contribute to the conceptualisation of PGI and its systemic assessment and integration into urban and open space planning.

This dissertation's work is related to the larger research project 'Rapid Planning, sustainable Infrastructure, environmental and resource management for highly dynamic metropolises' (2014-2019), which the author participated in as a research assistant from January 2015 to August 2019. The project was funded under the umbrella of the Future Megacities Research Programme of the BMBF. The consortium consisted of 11 German research institutions[1] and UN-Habitat and collaborated with partners in three case cities: Da Nang, Vietnam; Kigali, Rwanda; and Assiut, Egypt. The 'Rapid Planning' project focused on detecting and deciphering the urban metabolism of fast-growing cities and developing a rapid 'trans-sectoral' urban planning methodology. Participating in the project enabled research missions, data collection and access to existing local data. The collaboration between the consortium and local partners contributed significantly to the author's understanding of urban metabolism, remote sensing and simulation models.

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[1] Besides Technical University of Berlin, other university partners were Frankfurt University of Applied Sciences, Brandenburg University of Technology (BTU), Ostfalia University of Applied Sciences, University of Stuttgart and University of Tübingen. Other partners were AT Association (project management), Institute for Automation and Communication (ifak), Institute for Eco-Industrial Analysis (IUWA), IZES gGmbH and Institute for Energy and Environmental Research (Ifeu).

Experiences and data collected during the study period provided the chance to solidify the approach of PGI in the context of Da Nang.

1.2 Research gap

Researchers and planners have increasingly recognised the development and maintenance of green infrastructure in city regions as potentially improving living conditions for humans and nonhuman species (Benedict and McMahon, 2002; Hansen, 2018; Tzoulas et al., 2007). Similarly, assessing and strengthening urban food systems to tackle questions of sustainability and improve access to culturally adequate and nutritious food is an emerging topic of urban planning. An increasing number of cities have city-wide green space strategies and an urban food system strategies (Morgan and Rachel Santo, 2018; Wiskerke, 2015).

However, in the reality of urban planning, allocating precious space for urban agriculture is often neglected. Elements of urban agriculture are spatially dispersed across the city and vary drastically in size (Smit et al., 2001a). Urban agriculture projects are often carried out at an individual scale, but city-wide inventories, as in strategically assessing urban agriculture at a city-wide-scale, are missing (Zeunert, 2018). Practices of urban agriculture are likely of informal character (FAO, 2003). Current investigations in the social sciences are often based on surveys with limited references to geodatabases (FAO et al., 2018; Zezza and Tasciotti, 2010). Hence, existing urban agriculture is poorly inventoried and not formalised, making urban agriculture less likely to resist urbanisation (Zeunert, 2018). Regarding the realm of green spaces and potential green infrastructure, cities are more likely to have a certain extent of geographical inventory in the form of land use information and planning systems as there is a longer planning tradition. However, rapidly urbanising regions, particularly in the Global South, lack cadastral data and green space inventories (McLaren, 2015, 2011), and green spaces in these regions are often characterised by high shares of urban agriculture (Coronel et al., 2015; Thebo et al., 2014).

Further research is needed on how to comprehensively assess spaces and the functioning of urban agriculture as well as on the potential connection between urban food systems and green infrastructure. This hybrid approach could result in better-informed political and societal negotiation processes, reveal the potential contribution of PGI and ease its implementation into urban planning processes.

1.3 Case study: Da Nang

The research assumptions are examined using the example of Da Nang, Vietnam. The city is expected to more than double its population by 2030, jumping from one to two and a half million, and it is in the process of steering and managing rapid urban growth in the future (DOC, Da Nang, 2015). Da Nang can be considered a magnifying glass for global changes. Vietnam is one of the countries most hit by climate change worldwide due to sea-level rise and coastal flooding as well as prolonged droughts (IPCC et al. 2018, 231). The region hosts an abundance of species, some of are of critical biological importance which requires suitable conservation strategies (Olson and Dinerstein 2002). Moreover, Da Nang is located at the estuary of a large river system with prime agricultural areas, which are increasingly scarce worldwide resources due to urbanisation (Bren d'Amour et al., 2016).

Green spaces and urban agriculture

Da Nang, like other Vietnamese cities, does not have a long history of planning green spaces in urban areas. Designated green spaces have only been established in the past 20 years along watersides, particularly along main rivers and beaches (Bui Huy Tri, 2018). Nonetheless, the city has ambitious goals, and the current Urban Masterplan for 2030 states the goal to establish 12 m^2 of green space per person (DOC, Da Nang, 2015, pp. 78, 86).

At the same time, Da Nang has a lively tradition of urban agriculture among numerous social groups. All over the city, neighbourhoods are characterised by rooftop gardens and vegetable patches on any type of open space or vacant lot. The local diet typically includes a high rate of low- to unprocessed vegetables, fruit and herbs. This benefits the local so-called 'safe vegetable' movement, where producers meet Viet GAP (Good Agricultural Practice) standards and produce in close proximity of consumers to build trust (Quan et al., 2013).

Planning framework

Currently, local planning authorities do not consider urban agriculture as a valid type of green space. The Masterplan solely demarcates an area outside the urbanised domain as 'agriculture and villages'(DOC, Da Nang, 2015). However, the municipality's ambitious goals regarding green spaces and the fact that urban agriculture is very much established socially suggest that it is fruitful to combine both to develop a local PGI planning approach.

1.4 Research objective

Emerging approaches to urban planning that respond to the challenges of the Anthropocene (urban metabolism perspective, urban food system and green infrastructure) each shine a different light on how urban agriculture contributes to the well-being of urban residents and sustainable urban development. However, there is almost never an 'inventory' of urban agriculture in cities, and urban agriculture seems to often be disregarded as dispensable and informal by planning authorities. This lack of information and consideration jeopardises urban agriculture's continued existence and prevents its operationalisation in overarching strategic plans.

This research anticipates that a better understanding of the potential of urban agriculture – both in terms of a multifunctional and collaboratively created and managed green space that adds to a larger green infrastructure network and in terms of a more sustainable management of urban resources and optimising the city's urban metabolism – could lead to urban agriculture's increased valorisation and better-informed planning.

This research's objective is to outline a conceptual PGI approach drawing from the establishing approaches of green infrastructure and urban food systems. The approach is exemplified using the case of Da Nang, and this study is guided by the following research questions:

- Creating a spatial planning base: How can urban agriculture be better characterised and assessed in relation to its spatial dimensions?
- Understanding urban agriculture's role in the city's urban metabolism: How much food is produced now, and how much food could be produced if urban agriculture were integrated into rapid urban development as a PGI and part of a green infrastructure system? What are fruitful interlinkages to other urban infrastructures that optimise the city's urban metabolism?
- Envisioning PGI: How could these types of spaces look, and how could their potential contribution to local development goals being highlighted? What planning steps were necessary to further elicit this vision of PGI?

1.5 Structure of the thesis

This thesis begins with a literature review of current overarching challenges in the Anthropocene and visions and approaches for addressing them. An overview of scientific findings on human-induced planetary alterations and their consequences for resource utilisation (particularly in food systems) and land use practices is presented, along with the discourse on the relationship between urban and natural systems (Chapter 2). Following this, conceptual approaches and guiding principles offering new perspectives on exchange processes between urban and natural systems are discussed. *Urban metabolism analyses* offer an approach to creating a systemic and holistic understanding of the exchange processes. *Urban food systems*, as a sphere of the urban metabolism, have started to become a topic in urban planning, particularly regarding the physical appearance of *urban agriculture*. The *role of infrastructure* in facilitating urban resource flows is discussed, culminating in a reflection on the planning approach of *green infrastructure* and the extent to which *productive green infrastructure (PGI)* is currently conceptualised (Chapter 3).

In *Part II,* this work's understanding of PGI is derived based on a literature review of green infrastructure and urban food system planning. Combining both approaches allows for better understanding of urban agriculture and may benefit the assessment and operationalisation of its oftentimes dispersed and informal elements. Selected examples of green infrastructure and urban food system planning are analysed, particularly spatial assessment of urban agriculture and other green spaces. The potential contributions of PGI for a sustainable urban metabolism and the well-being of urban residents as well as remaining challenges for PGI's implementation are also laid out (Chapter 4).

Part III examines the PGI approach in the case of Da Nang. The methodology comprises a series of interconnected steps, with a brief overview of these given in Chapter 5. Based on a literature review and field research, a general overview of Da Nang's social-ecological system is introduced (Chapter 6), followed by an analysis of existing plans, policies, development goals and PGI-related planning procedures (Chapter 7). The case study is than used to exemplify the assessment of existing practices of urban agriculture by identifying characteristic typologies through an interlinked workflow of mappings and geodata processing; this deepens understanding of how the spaces contribute to the city's food supply (Chapter 8). The findings lay the foundation to further conceptualise the relation of urban agriculture to the urban metabolism. Over the course of the 'Rapid Planning' project, a simulation model of Da Nang's urban metabolism was developed to explore potential future developments with urban agriculture as part of the infrastructure system (Chapter 9). In a further step, as a spatial planning approach green infrastructure is used to draft a vision of how urban agriculture could be anchored in the region as a PGI. Model-like assumptions from the scenario simulation are further elicited by drafting spatial designs for two sites. Additional planning steps and linkages to the existing planning framework and procedures are outlined (Chapter 10).

In *Part IV*, based on the PGI approach in Part II and the Da Nang case study in Part III, relevant working steps to grasp practices of urban agriculture and operationalise them as a PGI are summarised as a model approach that could be transferred to other regions (Chapter 11). In the last chapter, the potential contribution of PGI to tackling global challenges is elaborated, and the methodologies explored to assess and operationalise PGI in the case study are critically discussed. The chapter ends with an outlook on future research and practice (Chapter 12).

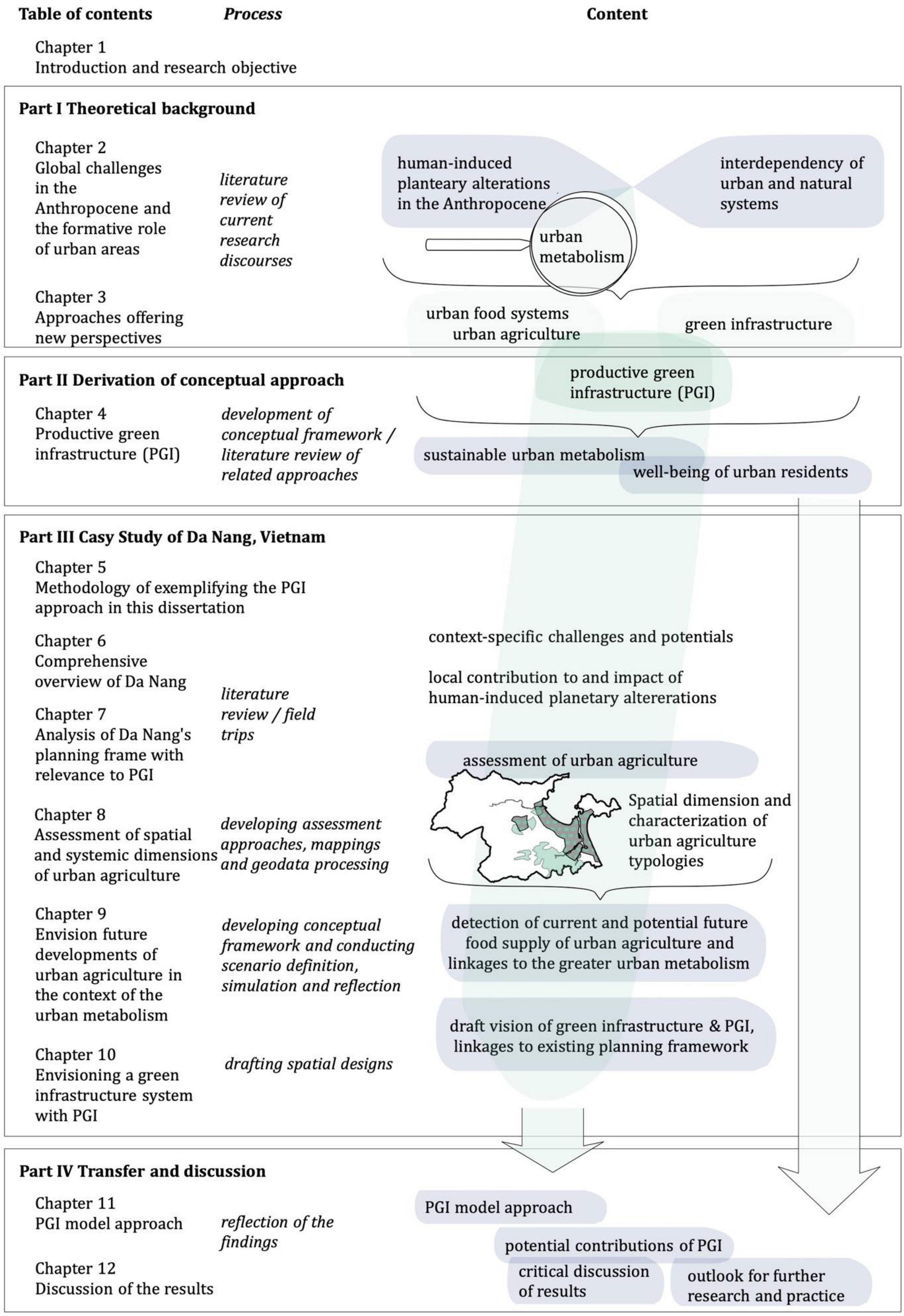

Figure 1 Structure of the dissertation

PART I THEORETICAL BACKGROUND

2 GLOBAL CHALLENGES IN THE ANTHROPOCENE AND THE FORMATIVE ROLE OF URBAN AREAS

An underlying understanding in this work is the interdependency of urban and natural systems as relates to a shared metabolism of materials and energy that condenses in urban areas (Giseke, 2018; Swyngedouw, 2006). The following chapter gives an overview of the drivers (2.1) and negative implications (2.2) of recent planetary alterations that have given rise to the Anthropocene. In both sections, the formative role of urban areas as well as the consequences they face are synthesised. Furthermore, the role of resource utilisation in shaping metabolic exchange processes is illustrated. As one sphere of the metabolism, the way urban food systems are organised particularly drives global change (2.3). Finally, the interdependency of urban and natural systems in terms of space and flows is elaborated (2.4).

2.1 Human-induced planetary alterations in the Anthropocene

The multi-layered relationship between urban and natural systems has become increasingly imbalanced in the past century. The phenomena of global urbanisation, population growth, and increasing resource consumption per capita due to rapid globalisation and industrialisation have each affected the global metabolism and have caused negative implications on the biosphere (see Figure 2). Humanity has become a major driving force of planetary changes, leading to the proposal of renaming the current geological epoch the 'Anthropocene' (Crutzen, 2002; Crutzen and Stoermer, 2000).

Rapid changes that characterise the Anthropocene include (IPBES, 2019; IPCC et al., 2018; Sachverständigenrat für Umweltfragen, 2019; Steffen et al., 2015; Working Group "Anthropocene" of the International Commission on Stratigraphy, 2019) the following:

- drastic changes of land cover (Ellis and Ramankutty, 2008) associated with urbanisation and agriculture, with a heavy increase in erosion, sediment transport and sealing of soils;
- global dispersion and accumulation of residues/new materials such as concrete, fly ash, and plastics, with 'Great Pacific Garbage Patches' (Law et al., 2010) in the ocean representing a well-known and increasingly problematic phenomenon;
- sudden anthropogenic disruptions of the cycles of elements such as nitrogen, carbon and phosphorus, with consequences such as eutrophication and acidification of ecosystems;
- negative implications on the biosphere and in particular global warming, and reciprocal processes of biodiversity degradation.

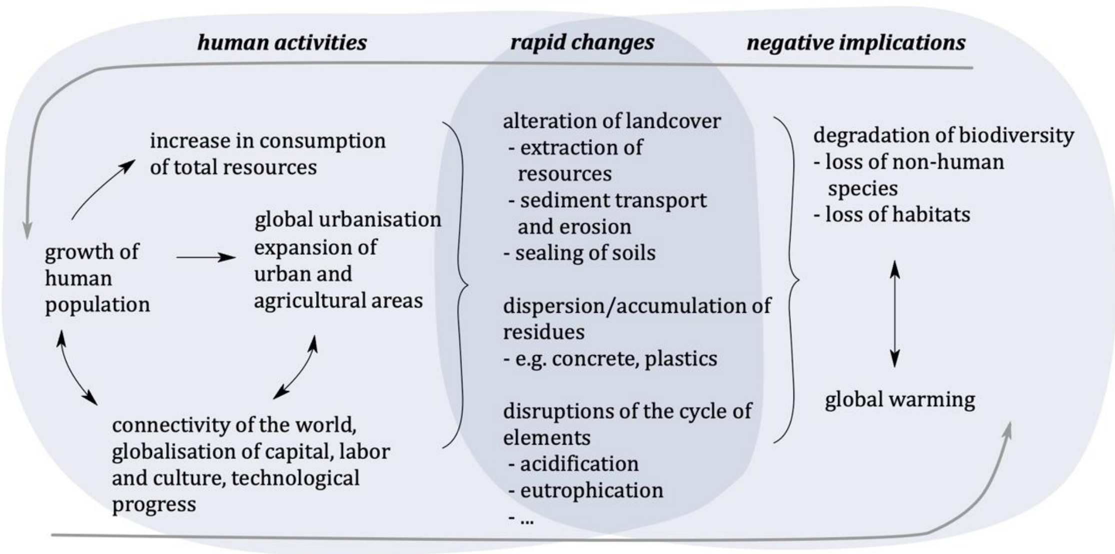

Figure 2 Diagram of human-induced planetary alterations

Box 1) Disambiguation of Anthropocene

Definition of Anthropocene

Anthropocene is a proposed and soon to be established name for the current geological epoch, which replaces the Holocene epoch that began 11,700 years ago after the last glacial period. The new epoch is a result of human impact that has intensified significantly since the onset of industrialisation, emerging as the most influential factor on Earth and inscribing itself in the Earth's geological depths.

Development of the concept of the Anthropocene

Atmospheric chemist Paul J. Crutzen was the first to coin the term 'Anthropocene' in 2000 (Crutzen and Stoermer, 2000). His proposal draws from the long history of the relationship between humankind and nature. Some noteworthy milestones include the following moments.

- Proposal of an 'Anthropozoic era' (Federighi, 2013) by geologist Antonio Stoppani (*1824 † 1891) around the time when the 'Great Acceleration' (Steffen et al., 2015) started. Stoppani claimed that 'The creation of man constitutes the introduction into nature of a new element with a strength by no means known to ancient worlds . . . We are only at the beginning of the new era; still, how deep is man's footprint on Earth already!' (Federighi, 2013, p. 348).
- In 1896, scientist Svante Arrhenius expressed concern about the effects of increasing CO2 concentration in the atmosphere (Arrhenius, 1896).
- In 1972, the Club of Rome issued their thoughts on possible consequences for civilization caused by overusing resources, acknowledging the limits of growth (Meadows et al., 1972).
- From 1992 on, the global scale of human alteration became more publicly known after it was on the agenda of the United Nations Conference in Rio de Janeiro (United Nations Conference on Environment, 1992).

While continuing to attest to the growing impact of humans on Earth, the Anthropocene concept emphasises the global scale of these effects and, more importantly, it asserts the inseparability of humanity and natural systems.

23 years after Crutzen's initial proposal, relabelling the current geological epoch is still a hot topic. The decision-making authority for geological epochs is the International Commission on Stratigraphy (ICS). In May 2019, the majority of the Anthropocene Working Group in the ICS voted in favour of treating the Anthropocene as a formal chronic-stratigraphic unit (Working Group "Anthropocene" of the International Commission on Stratigraphy, 2019).

International institutions such as bodies associated with the United Nations started using the term Anthropocene. For instance, the International Panel on Climate Change (IPCC) refers to the Anthropocene in their reports on climate change (IPCC et al., 2018).

In addition to the geology field, the Anthropocene has emerged as an overarching topic for transdisciplinary research regarding environmental sciences, technological sciences, social sciences, law, politics, history, philosophy and cultural sciences and has developed a life of its own within different 'narratives' (Dürbeck, 2018). The 'Haus der Kulturen der Welt' in Berlin, a national centre for the discussion and presentation of international arts and cultures, initiated 'The Anthropocene Project' in 2013, followed by the project 'Technosphere' (Haus der Kulturen der Welt, 2019); these projects contributed to foregrounding the Anthropocene in cultural studies and for the public.

In 2007, a set of 12 Great Acceleration graphs were published that demonstrate socio-economic and Earth System trends from 1750 onwards (Steffen et al., 2007). The graphs have become iconic images of the Anthropocene as they capture the comprehensive nature of post-1750s changes. The graphs were updated in 2015 to differentiate between OECD countries and those with emerging economies (Steffen et al., 2015).

Per Crutzen, the beginning of the Anthropocene should be placed at the end of the 18th century when James Watt invented the steam engine. Current debate favours the mid-20th century as the starting point of the Great Acceleration, with the nuclear bomb tests marking the sharpest and most globally synchronous signals of human-induced planetary alterations (Working Group "Anthropocene" of the International Commission on Stratigraphy, 2019).

Scientists and philosophers have also proposed other terms for the current epoch. For instance,

- Jason Moore proposed 'Capitalocene', underlining the dominant role of capitalism as a 'multispecies affair' that consists of a 'relation of capital, power and nature as an organic whole'. He emphasised that not all humanity as an undifferentiated whole can be held responsible for this capitalist development and that the Anthropocene idea disregards inequality, imperialism, and patriarchy (Moore, 2016, pp. 81–82).
- Donna Haraway proposed the 'Chthulucene', referring to the 'diverse Earth-wide tentacular powers and forces'. The term entangles 'myriad temporalities and spatialities and myriad intra-active entities-in assemblages – including the more-than-human, other-than-human, inhuman, and human-as humus.'

(Haraway, 2015, p. 160). Haraway argued that all 'critters' (not only humans) should join forces to ensure survival on Earth.

- Donna Haraway also proposed the 'Plantationocene', referring to the devastating transformation of different types of land uses (farms, pastures, forests) into extractive and enclosed plantations (Haraway et al., 2016).

While the term Anthropocene is debatable, it has steered attention and political volition by positioning Earth and humanity – some of the largest imaginable categories – into a causal, reciprocal relationship. The term has succeeded in moving previously disparate discussions in the social sciences, humanities, engineering, and natural science disciplines toward a shared recognition of problems (Goeke, 2017).

2.1.1 Global urbanisation

The growth of the human population and urban areas can be seen as both a manifestation of changes during the Anthropocene and at the same time as a significant driver of changes. Overall, average per-capita consumption of resources has remained relatively stable, with an annual increase of 0.5% globally since the mid-1970s. However, there are drastic regional differences. Since the 1970s, several comprehensive studies on urban metabolism (see 3.1) in industrialised countries have been carried out, revealing increased resource use per capita. Water and wastewater flows increased, and material inputs such as plastics, iron, steel, paper cement have multiplied since the 1970s (Kennedy et al., 2007).

However, the 24% increase in resource use since the mid-1970s is considered to be greatly driven by exponential population growth (Lin et al., 2018). The world population has more than doubled since 1950, from 2.54 billion to 7.63 billion people – with 9.77 billion being the estimated maximum by 2050. While growth in more developed regions is predicted to stagnate at around 1.3 billion until 2050, growth in less developed regions is predicted to increase from 1.72 billion in 1950 to 8.47 billion in 2050, representing a fivefold increase in just 100 years (United Nations, Department of Economic and Social Affairs, Population Division, 2019).

Urbanisation

Population growth, industrialisation and the globalisation of capital, labour and culture go along with complex migration processes and global urbanisation.

> Over the past 30 years, the world has been experiencing an unusually expansive and reconfigured form of urbanisation that has defined a distinctively global urban age – one in which we can speak of both the urbanisation of the entire globe and the globalisation of urbanism as a way of life. (Soja and Kanai, 2014 p.142)

According to the United Nations, more than 55% of the population lives in urban areas, and this share is expected to rise to 66% by 2050. The number of megacities with more than 10 million inhabitants rose from 18 in 2000 to 33 today. Moreover, in 2000, there were 371 cities with at least one million inhabitants; currently, there are 548, and based on projections there will be more than 700 in 2030 (United Nations, Department of Economic and Social Affairs, Population Division, 2019, 2019). As urban and rural borders become increasingly blurred, urban areas stretch into 'urban galaxies' (Soja and Kanai, 2014).

Apart from the local manifestation and physical appearance of growing cities, urbanisation has created an impact on a global scale and affects the availability of resources, including food.

> […] if a global urban age is indeed currently dawning, this circumstance cannot be understood adequately with reference to the formation of global cities or large-scale megacity regions, but requires systematic consideration of the tendential, if uneven, operationalization of the entire planet- including terrestrial, subterranean, oceanic and atmospheric space – to serve an accelerating, intensifying process of urban industrial development. (Brenner, 2014a, p. 21)

Utilisation of natural systems

The expansion and thickening of urban areas is interdependent on the utilisation and exploitation of natural systems described as 'specialized regions of service and supply' (Langhorst, 2016), 'operational landscapes' (Brenner, 2014a), 'life support systems' (Odum et al., 2004) or 'colonized environments' (Fischer-Kowalski and Haberl, 1993).

In essence, all of the terrestrial and some of the aquatic sphere have been colonised as they have been subdivided into national states (except for the Antarctic). In a narrower sense, the process of colonisation means an intentional change of natural systems to render them more exploitable. Oswald and Baccini coined the term *'global hinterland',* meaning any territory outside the urban system that is needed to import or export material and energy (Oswald et al., 2003). By 2008, it was found that more than 75% of Earth's ice-free land showed evidence of alteration due to human residence and land use (Ellis and Ramankutty, 2008).

The development of infrastructure for wastewater, water, energy and transport are crucial for global urbanisation as these connect urban areas and their service regions. Hence, the expansion and densification of a global infrastructure mesh has enabled the decoupling of regional supply-and-disposal chains (Langhorst, 2016; Prytula, 2011).

2.1.2 Global interconnectedness

Quantification of urban residents and the growth of urban areas is just one aspect of global urbanisation. Whether humans are located within, near or far away from dense urban settlements, they require increasing amounts of resources and have been more and more diligent in trading and exchanging materials, goods, information and data across the world (Lin et al., 2018).

Post-industrial service or knowledge societies have outsourced large parts of their industrial production and associated emissions to industrial emerging countries. The global imbalance in the possibility of using resources has not only led to an unequal distribution of wealth and poverty but also to a disparity between the causes and effects of social and ecological consequences (Prytula, 2011).

The current revolution in information and communications technology has accelerated these processes and led to transnational investments in the production of goods and services and information (Baccini and Brunner, 2012; Soja and Kanai, 2014). The current model of urbanisation is largely driven by capitalist forces and heavily leans on the extraction and consumption of fossil fuels, which directly implicates a form of 'global ecological plunder that has permanently altered the Earth's climate, while infiltrating the Earth's soils, oceans, rivers and atmosphere with unprecedented Ievels of toxic waste' (Brenner, 2014a, p. 21). Jason Moore calls this the concept of 'Cheap Nature'. Land and labour are appropriated and incorporated into the global cash nexus, which serves as the basis for capital accumulation – a strategy that is about to be exhausted as global resources are not infinite (Moore, 2016, pp. 113–114).

Hence, the effects of global urbanisation are not contained within the territory of urban areas as cities have a global impact on material and resource flows and therefore on the climate, environment and society (Folke et al., 2011). Urban habits and consumption patterns are increasingly interacting with areas in completely different parts of the globe because related 'supply and service areas' (Langhorst, 2016) can be anywhere in the world; this effect is known as 'telecoupling' (Liu et al., 2013).

Current research can trace biodiversity loss to the consumption patterns of single countries. Small, industrialised countries like Luxembourg, the Netherlands and Japan are estimated to cause more than half of biodiversity loss outside their territory via indirect occupation of biocapacity. In other words, these countries' land use and land-related biodiversity footprints are displaced to other countries (Galli et al., 2015; Wilting et al., 2017).

2.2 Negative implications on the biosphere

Human-induced alterations, such as changes in land cover, dispersion of residues/new materials and sudden anthropogenic disruptions of the cycles of elements, have led to problematic and reciprocal changes in the biosphere such as global warming and alterations to the biosphere's structural and genetic integrity that cause degradation and extinction of nonhuman species. In very different magnitudes, these alterations affect humanity depending on an individual's place of residence and wealth, creating and reinforcing environmental and social inequality.

2.2.1 Climate change

2.2.1.1 Overall changes in temperature over time

One of the most significant aspects of planetary change regards temperature. The Holocene began after the last interglacial period 11,700 years ago and is characterised by a moderate climate. Human activities have increasingly affected the climate since the Industrial Revolution in the mid-18th century. Human-induced warming caused an approximate increase of 0.85 °C of global average surface temperature between 1880 and 2012. It likely reached 1°C increase by 2017 (IPCC et al., 2018, p. 201), see Figure 3. The temperature changes are considered human-induced given that changes in solar and volcanic activity have been mostly absent during this period. As such, the temperature changes are caused by the rapidly increasing emission of greenhouse gases like carbon dioxide, methane and nitrous oxide.

These changes affect natural systems and cause unprecedented risks for humanity, especially vulnerable groups. Against this background, 196 parties at the 2015 United Nations Climate Change Conference in Paris adopted the goal to limit global warming to preferably 1.5 °C. According to the IPCC, further warming will most probably lead to other profound alterations such as increases in extreme weather events like droughts and floods, sea-level rise and biodiversity loss; these alterations might reach a magnitude beyond remediation through natural systems (IPCC et al., 2018).

Several possible scenarios are discussed in the scientific literature. A worst-case scenario would be a collapse of civilization in an 'Anthropocene of devastation' or 'Hothouse Earth' characterised by a breakdown in the important functional relationships of the geosphere-biosphere complex of the Holocene (Ehrlich and Ehrlich, 2013; Sachverständigenrat für Umweltfragen, 2019; Steffen et al., 2018).

The processes of the urban-natural relation are reciprocal. Due to changes in land cover, the biosphere's resilience towards extreme weather and the capability for climate change mitigation of natural systems have decreased. Because of land degradation, particularly in coastal habitats, 100–300 million people are at increased risk of hurricanes and floods (IPBES, 2019, p. 11). Regarding climate change mitigation, marine and terrestrial ecosystems are a sinks to anthropogenic carbon emissions. Ecosystems sequestrate an amount that is the equivalent of 60 % of global anthropogenic emissions. This ability is limited due to progressing deforestation and drainage of wetlands (IPBES, 2019, p. 10).

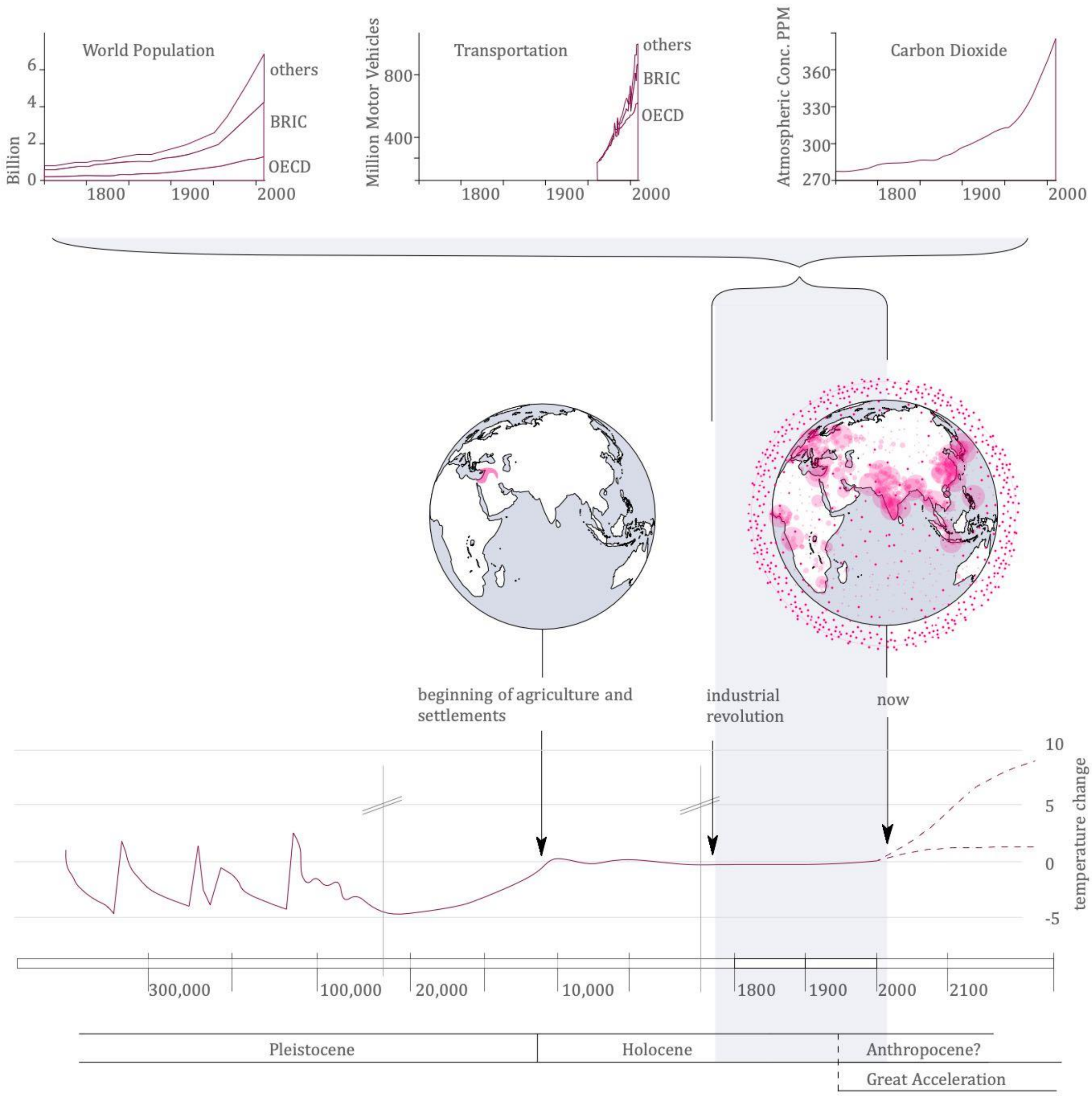

Figure 3 Time beam of Holocene, Anthropocene and the Great Acceleration, based on (Steffen et al., 2015; Burke et al., 2018; IGBP, 2019)

2.2.1.2 Climate change and urban areas

Urban areas particularly suffer from climate change-related risks. Urban density, building material properties and the degree of soil sealing correlate with surface air temperature. Additionally, cities emit anthropogenic heat resulting from space heating and cooling and vehicle exhausts, among other activities. This produces the so-called *urban heat island effect,* which potentially induces heat stress among urban residents (Aromar et al., 2014).

Moreover, it is estimated that rainfall intensity will increase in many areas, causing more frequent urban flooding (Willems, 2012). Urban flooding is therefore an increasing challenge given that many cities, including Da Nang, are located in coastal and low-elevation zones. Within these cities, structures built on infilled soils in lowlands are more prone to flood hazards than those built on consolidated material (Aromar et al., 2014; Fenner, 2020). The intensity of urban flooding correlates with surface imperviousness and the catchment capacity of installed drainage systems. In fact, the installation of urban drainage systems can make cities more vulnerable to damage from extreme rainfall when capacities are exceeded. In the case of combined systems for runoff and sewage water, extreme rainfall can lead to an overflow and potential health risks (Willems, 2012).

2.2.2 Degradation of biodiversity

2.2.2.1 Overall changes in biodiversity over time

Earth's most distinctive feature is the existence of life; the most extraordinary quality of life is its diversity in terms of the variety of genes, species and functional traits (Cardinale et al., 2012). Mounting evidence points towards an accelerating loss of diversity due to human actions. The expansion of land use for urbanisation and agriculture is one of the most obvious alterations. About 75% of terrestrial land has been altered, 66% of marine land cover has been impacted meanwhile and 85% of wetlands have been lost (IPBES, 2019, p. 11). These direct changes as well as their indirect changes (dispersion of materials, disruption of the cycles of elements and subsequent climate change) are the main reasons for declining biodiversity. Rates of biodiversity losses are about 100 to 1,000 times higher due to human activities compared to natural extinction processes. According to the Living Planet Index,[2] vertebrate populations alone have declined by 60% since the 1970s (WWF et al., 2018, p. 92). According to the latest UN assessment, an average of about 25% of species are threatened, and approximately one million species face extinction. The abundance of native species in most terrestrial habitats decreased at least 20% since 1900 (IPBES, 2019, pp. 11–12).

Consequences are complex as species exist and evolve in interrelated networks of ecosystems (Capra, 2015). Research is attempting to unravel the relationship between the functioning of ecosystems and the diversity of their living components. Ecosystems consist of living organisms and their non-living environment that interact by exchanging energy and material flows. The network is based on *producers*, which is mostly plants that manufacture food from inorganic substances; *consumers* such as herbivorous and carnivorous animals that digest organic material; and *decomposers* of organic matter (Odum et al., 2004) (see 3.1.2.1).

The degradation of biodiversity compromises the efficiency and stability of these exchange processes. Degrading communities are less able to capture resources such as nutrients and water, convert these resources into biomass and, in turn, sequestrate carbon and potentially buffer climate warming (Cardinale et al., 2012).

The relationship between an ecosystem's stability and biodiversity loss is non-linear: while initial losses can be compensated for, increasing losses lead to accelerating change (Cardinale et al., 2012). The magnitude of biodiversity loss is a complex process that is estimated to be as severe for ecosystem functioning as other anthropogenic drivers such as changes in atmospheric CO_2 or water availability (Tilman et al., 2012).

2.2.2.2 Biodiversity and urban areas

Urbanisation entails the loss of green spaces and often decreases biodiversity as well as opportunities for humans to experience nature. At a fine spatial scale, many studies have identified a negative correlation between the density of a human population and biodiversity. Urbanisation leading to dense urban areas with scarce and structurally simplified green spaces results in a low number of plants and thus birds, mammals, reptiles, invertebrates and soil microbiota (Faeth et al., 2011; McKinney, 2008).

On the contrary, at the scale of city regions including peri-urban areas with heterogeneous habitats, biodiversity levels often increase over the course of human settlement (McKinney, 2008). In some cases, cities are known to host a significant proportion of rare, red-list species (Vierikko et al., 2017). One underlying cause of this might be the 'disturbance hypothesis', with urbanisation displaying a gradient of disturbance. Some native species tolerate moderate human interference and are preserved, and alteration of habitat structures can also attract additionally newcomers; this holds true for specific species and applies more so to plants than vertebrates, which often need larger and interconnected spaces to maintain population sizes. Another factor for increased biodiversity in urban areas is the introduction of non-native plant species through human activities such as gardening or the dispersion of seeds along transportation routes (Faeth et al., 2011; McKinney, 2008). An additional observation is that for birds and arthropods, urbanisation generally decreases diversity but often increases abundance compared to more rural areas in the region (Faeth et al., 2011).

Still, due to urbanization, the emergence of entertainment options such as television, computer games and the internet, urban residents, and especially children, tend have fewer nature experiences (Soga and

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[2] An indicator of the state of global biodiversity that tracks the populations of thousands of mammals, birds, fish, reptiles, and amphibians and that is managed by the Zoological Society of London in cooperation with the World Wide Fund for Nature (WWF).

Gaston, 2016). A global trend that has been termed 'experience extinction' refers to alienation from nature leading to a cycle of disaffection, assuming that a lack of nature experience means people care less about nature (Pyle, 1993). Many studies have confirmed a strong connection between human mental and physical well-being and experiences of nature (Cox and Gaston, 2018).

2.3 Impacts of current resource use organisation

2.3.1 Exceeding biocapacity

The Anthropocene marks a turning point regarding the global scale of human intervention. One widely approved measure for tracking the use and overuse of natural resources is ecological footprint, which sums all human activities requiring productive area (Wackernagel et al., 1999) (see Box 3). Since 1961, the productive area that can regenerate what people demand (biocapacity) has increased by 0.5% per year – meaning an expansion and intensification of land use. Humanity's ecological footprint has still outpaced this growth by an average yearly increase of 2.1%.

Total ecological 'overshoot' began in the 1970s. By 2014, theoretically, 1.7 planets were needed to sustain the demand on Earth's natural resources and to regulate carbon emissions (Global Footprint Network, 2019). The distribution of resource use reveals significant geographic differences. Ecological footprint per capita in the Asia-Pacific region has increased slowly but has remained low and stable in recent years. However, the global ecological footprint has risen quickly due to immense population growth (Lin et al., 2018).

In the long run, surpassing the regeneration level will lead to unsustainable depletion of stock and reductions in available input material. Under a combination of excessive demographic pressure and unsustainable land use practices, some regional land and water systems face a risk of progressive collapse of their productive capacity (FAO, 2013). Moreover, human demand on the biosphere is linked to direct threats to biodiversity, which is declining at an unprecedented rate (Wilting et al., 2017) (see 2.2.2).

The availability of resources and their interconnectedness to land use and global trades vary. For example, water use is increasing dramatically on a global scale (Steffen et al., 2015). While there is no scarcity of global water, many regions increasingly face local water shortages due to climate change (FAO, 2017a). At the same time, other resources such as food, energy and consumer goods are much more connected to global trade networks via imports and exports. While it is believed that pre-modern cities incorporated resources within a perimeter of 30 km 'just in time', today's cities are connected to resources worldwide (Barthel et al., 2016a).

2.3.2 Food systems as drivers of global change

Food systems – that is, the production, processing, distribution, consumption of food, accumulation, and valorisation of food residues (see 3.2) – have been identified to be among the most influential drivers of global change. The growing urban population has led to major socio-economic shifts. Increasingly centralised networks supply a growing proportion of the world's food. Increasing affluence has also introduced dietary changes such as high demand for meat and processed food. The satisfaction of urban consumer demand for these types of resource-intensive food at low costs happens at the expense of equitable and sustainable development (Cesari et al., 2016; Jennings et al., 2015).

Cities are both dependent and competitive with their 'service regions'. Urban growth has a qualitatively and quantitatively negative impact. The way food is produced undermines the biosphere's capacity for future food production. Current approaches to agriculture largely compromise the self-regenerating quality of natural systems. Unsustainable management practices such as nutrient mining, erosion, and surface and groundwater pollution from improper use of fertilisers and pesticides erode ecosystem functioning and lower production capacity in the long run (FAO, 2013; Fischer-Kowalski and Haberl, 1993, p.; Haber, 2016).

Moreover, urbanisation has reached an extent that physically decreases agricultural production areas on a global scale. As many cities were founded near fertile land (Smit et al., 2001a), the expansion of urban areas on this type of increasingly scarce soil is impacting the accessibility of food and therefore food security. Spatial analysis of high-quality land use datasets from the year 2000 revealed that 5.9% of total cropland is situated within urban areas, and 60% of the total irrigated cropland area is located within a 20-km buffer zone of urban areas (Thebo et al., 2014). The loss of croplands between the years 2000 and 2030 will be approximately 2% globally, with substantial regional disparities as most losses occur in Asia and Africa. Vietnam, for example, is estimated to lose 10% of its total cropland, accounting for 15.9% of production loss as suburban cropland has been proven to be 1.41 times more productive than the regional average (Bren d'Amour et al., 2016).

Growing demand for land has caused deforestation and loss of biodiversity (FAO and WHO, 2019). Research has indicated that food consumption and related land use accounts for the most loss of biodiversity, compared to the demands for housing, transport, goods and services. In turn, biodiversity loss is interrelated with ecosystem functioning and biocapacity (Wilting et al., 2017) see 2.2.2). Beyond land, the production of food is dependent on the availability of other resources, including water and fertiliser. Agriculture accounts for about 70% of global freshwater withdrawal. Moreover, the entirety of global food systems is estimated to be responsible for 20%–35% of greenhouse gas emissions (FAO, 2017a) due to the packaging, processing, transport, storage, retail, waste disposal and emissions from the livestock sector (Jennings et al., 2015).

2.3.3 Impacts of mismanaged food systems on human well-being

In the past century, the productivity of agriculture has increased. With more globalised food chains as well as the mechanisation and intensification of cultivation processes, the proportion of undernourished people decreased from 24% in 1990–1992 to 14% in 2011–2013, though this remains a pressing issue. Today, an estimated 820 million people suffer from undernutrition, and a further 1.3 billion did not have regular access to nutritious and sufficient food in 2018 (FAO and WHO, 2019). Malnutrition occurs in the form of micronutrient deficiencies such as iron, folic acid and Vitamin A and results from limited diversity in diets and insufficient consumption of legumes, nuts, or specific fruits and vegetables. Worldwide, the combined effects of undernutrition and deficiencies are responsible for about 45% of deaths among children under five years of age (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

While undernourishment is generally declining, increasing obesity is now considered a pandemic (Monteiro et al., 2012). Obesity has outpaced being underweight. Indeed, approximately 30% of the global population is overweight, which renders individuals more prone to non-communicable diseases such as heart disease, stroke, diabetes and certain cancers. Obesity accounts for 2%–7% of healthcare spending in developed countries (Dobbs et al., 2014).

Rising obesity is connected to growing industrialised food systems and the availability of cheap and highly caloric but nutritionally deficient ultra-processed foods (Jennings et al., 2015; Moubarac et al., 2014). There has been a notable shift away from dietary patterns based on the preparation of unprocessed or minimally processed foods at home towards an increase in ready-to-consume ultra-processed food based on formulations of industrial ingredients containing no or small amounts of whole food (Monteiro et al., 2012; Moubarac et al., 2014).

The current state of the food system is characterised by a ‘triple burden of over-, under- and malconsumption all co-existing, often within the same region and country’ (Lang, 2010, p. 89).

Ensuring ‘access to food that is safe, nutritious and culturally appropriate in sufficient quantity and quality to sustain a healthy life in dignity’ – that is, ‘food sovereignty’, as proposed during the 1996 World Food Summit (cited in Timmermann and Félix, 2016) – to the estimated 10 billion people who will be alive at the end of this century without further exceeding biocapacity and under the conditions of climate change is one of the most pressing challenges. Incidents like sudden global food price spikes and the disruptions of supply chains during global crises such as the COVID-19 pandemic illustrate the vulnerability of globalised food systems.

2.4 Interdependency of urban and natural systems

As a whole, planetary alterations affect material flows, energy balance, biochemical cycles and the health of organisms and ecosystems. Understanding the interrelated planetary alterations and imagining possible future developments requires systemic thinking. Rapid changes of single components lead to reciprocal dynamics. Feedback loops can either increase or stabilise certain system dynamics (Prytula, 2011).

So far, some of the consequences of human action have been compensated by the biosphere's adaptability and resilience to a certain extent (see 2.2.2). However, progressive disturbance could lead to significantly more and qualitatively different changes in the world.

2.4.1 Conception of human-nature relations

Sociology has a long history of debating the extent to which humans are part of nature. Sociologists William Catton and Riley Dunlap rejected the 'human exceptionalism paradigm' and called for a 'new environmental paradigm' in light of increased attention to environmental depletion and the recognised 'limits of growth' (William R. Catton and Riley E. Dunlap, 1978).

Recent interpretations emphasise the simultaneity of nature and culture within the human being. Haraway introduced the term 'Natureculture' to reflect that nature and culture are inseparably interwoven (Haraway, 2003).

Haber describes humans as 'double beings' ('Doppelwesen'), drawing on Chakrabarty's point that 'you have to think of the two figures of the human simultaneously: the human-human and the nonhuman-human' (Chakrabarty, 2012; in Haber, 2016). Haber emphasises how humans are biologically just one among other species. The two essential features of every living being, including humans, are 1) use of nature in terms of nourishment and finding a habitat and 2) protection from nature, meaning that every creature strives to protect its own life from the threats of nature, such as competitors, predators and parasites. However, unlike other mammals, humans are equipped with a unique intellect and have the ability to project and plan. Advanced communication and knowledge production have formed human culture and have enabled humans to profoundly reorder natural systems. Through cultural evolution, humans have created their own type of environment. With rational, mostly economically controlled modes of use, humans suppressed or partly replaced regulatory processes of natural systems (Boyden, 2016; Haber, 2016).

2.4.2 New momentum sparked by the Anthropocene discourse

Since humans have been identified as a geophysical force of global warming, they are now part of the planet's natural history (Chakrabarty, 2012).

> The wall of separation between natural and human histories that was erected in early modernity and reinforced in the nineteenth century as the human sciences and their disciplines consolidated themselves has some serious and long-running cracks in it. (Chakrabarty, 2012, p. 10)

As human-induced planetary alterations (see 2.1) have reached a considerable magnitude, the interdependency between urban and natural systems cannot be contested. The Anthropocene implies a new epistemic constellation as it has become 'impossible to understand nature without society, and society without nature' (Becker, 2012, p. 4, referring to a statement of Ulrich Beck). Destabilising natural systems means destabilising humanity's basis of existence (Wieck and Giseke, 2018). As Haraway emphasised, there is no 'escape' to this current situation because 'the Earth is full of refugees, human and not, without refuge' (Haraway, 2015, p. 160).

- *Environment is dependent on humanity*: human-driven changes exceed those driven by the biosphere or geophysical forces. The future path of humans' actions will continue to significantly affect the planet (Folke et al., 2011; Rockström et al., 2009; Steffen et al., 2018).
- *Humanity is dependent on the environment:* on the other hand, today's civilisation only came into existence due to the planet's current conditions. A specific feature of the Holocene was the stability of natural systems. It was at the beginning of the Holocene that humanity started to settle. Lifestyles transitioned from hunting and gathering to agriculture and settlement in the Neolithic or Agricultural Revolution. The Anthropocene indicates a possible period with less stable conditions, which may compromise civilisation (Greffrath, 2019; Sachverständigenrat für Umweltfragen, 2019).

Interdependency is reflected in the exchange processes between urban and natural systems as part of an (urban) metabolism (see 3.1). More natural rural areas with features such as a high density of nonhuman organisms may be part of 'service and supply regions' (Langhorst, 2016) that are highly altered (e.g., agro-industrial landscapes): 'Human organisations are environment-making processes and projects; in turn the web of life shapes human organisation' (Moore, 2016, p. 79).

In recent discourse, the entirety of interdependent human societies and ecosystems are often described as social-ecological systems that connect the local to the global, with their exchange processes being shaped by ecosystem properties as well as societal frameworks (Andersson et al., 2014; Becker, 2012; Folke et al., 2011).

2.5 Summary and conclusion

Changes in land cover, dispersion of residues/new materials and sudden anthropogenic disruptions of the cycles of elements have reached an extraordinary magnitude following sharp acceleration since the 19th century. These alterations have led to problematic and reciprocal changes in the biosphere, ultimately jeopardising the survival of humans and other species (Steffen et al., 2015). Some changes have been compensated by natural systems, but progressing alterations could lead to significantly more and qualitatively different system changes (Rockström et al., 2009).

Scientists have proposed a new geochronological epoch, the Anthropocene, to acknowledge that humankind has become the most influential factor in essential planetary processes. Speculation on possible future development covers a wide range of possibilities, from a breakdown and even extinction of humanity to technological solutions (Dürbeck, 2018). In any case, continuous global warming will lead to premature termination of the Holocene and its moderate conditions (Sachverständigenrat für Umweltfragen, 2019).

The Anthropocene debate has sparked a rethinking of the separation of the urban and natural. Humans cannot distance themselves from nature but are part of the metabolism of materials and energy in urban areas (Giseke, 2018).

Resource utilisation, and food systems in particular, are major drivers of global change in terms of expansion of land use and malpractices that erode ecosystem functions, such as provision of resources, and climatic regulatory services as sinks of greenhouse gas and hydrological cycle regulators. These changes are interrelated with biodiversity degradation (Wilting et al., 2017).

To address social-ecological imbalances, cities need to decrease their impact on external territories and land-use-related biodiversity footprint. This thesis therefore explores the potential contributions of urban agriculture and the PGI approach.

3 APPROACHES OFFERING NEW PERSPECTIVES: URBAN METABOLISM, URBAN FOOD SYSTEMS AND GREEN INFRASTRUCTURE

The following chapter addresses conceptual approaches and guiding principles that offer new perspectives on the exchange processes between urban and natural systems. First, the overarching lens and planning approach of urban metabolism and the planning principles of sustainability and circular organisation are discussed (3.1). The emergence of urban food systems – which are a sphere of urban metabolism and a major driver of global change – as a planning concept (3.2) and the prevalence and role of urban agriculture as a type of tangible green infrastructure are examined. Infrastructures are highlighted as the most critical component of reorganising the urban metabolism. Existing path dependencies and approaches for alternative trajectories are illustrated (3.4). Finally, the potential of green infrastructures to connect the well-being of ecosystems and humans is discussed (3.5).

3.1 Urban metabolism

Urban metabolism describes the uptake, transport, and storage of all substances; the total chemical transformations within the system; and the quantity and quality of life of a city's inhabitants (Baccini and Brunner, 2012). The term refers to an approach to creating a systemic and holistic understanding of the urban-natural interrelationship by viewing cities within their societies and built structures as if they were (urban) ecosystems that exchange material and energy with their surroundings. This understanding entails that exchange processes can be reviewed and potentially optimised by mimicking the cycling of material and energy in natural ecosystems (Zhang et al., 2015). Equal emphasis is laid on analysing and reviewing the social system, which largely determines the exchange processes' stocks and flows (Dijst et al., 2018).

3.1.1 Urban areas as nodes of global metabolism

Urban development has become a driver of the Anthropocene. City regions, with their density of resource flows as well as their knowledge and creative potential, will be among the most important agents of survival on Earth. They are hubs of rapid changes and particularly affected by these changes at the same time (Sieverts, 2018, p. 35).

> The greatly elevated global metabolism and the rapidly growing demand for resources of a globally industrializing and urbanizing society make a more efficient use of urban resources indispensable. (Giseke, 2018, p. 200).

The metabolic perspective highlights cities as important action fields because many nodes of metabolic flows concentrate in these spaces. Cities have been conceptualised as 'as a process of de-territorialisation and re-territorialisation through metabolic circulatory flows, organised through social and physical conduits' (Swyngedouw, 2006, p. 106).

The urban metabolism approach deciphers interlinked geographies by understanding and locating the metabolic flows between life support systems (Odum et al., 2004), which is where resources are generated, respectively extracted and processed, and hubs of consumption and storage (Kennedy et al., 2011; Prytula, 2010). Acknowledging and understanding metabolic relations and their spatial extent is the basis for optimising material and energy flows through spatial planning and policymaking. These geographies – as cultivated or near-natural landscapes – as well as urban areas and their infrastructures gain agency. Their constitutive role regarding metabolic functioning and the production of space and culture are considered in the interactive urban-natural relation (Bennett, 2010; Gandy, 2004).

In the context of human-induced planetary alterations, cities are affected with different characteristics and magnitude depending on their local climate; environmental conditions; and their levels and efficiency of governance, agency and economic state (Kennedy et al., 2007). Looking at city regions offers a perspective on the local manifestation of global changes. City regions can be a field of action to improve the local urban metabolism and reduce environmental load.

> If people succeed in sufficiently discerning the environmental system of which they are part by exploring its potentials and adapting flexibly to it, they at least have the chance to survive in it, even if the system itself is subject to rapid changes. (Renn, 2017, p. 18)

3.1.2 Ecosystems of the biosphere and the technosphere

3.1.2.1 Ecosystems of the biosphere

The idea of *urban metabolism* draws on the theory of ecosystems, in which living organisms and their non-living environment inseparably interrelate and interact (Kennedy et al., 2011; Prytula, 2011). The network of ecosystems consists of regenerative, adaptive, self-organising systems. Ecosystems are defined by flows of energy and cycling of materials between living and non-living elements as well as *within* living elements (Odum et al., 2004, p. 18). The main energy input stems from the Sun. Solar energy is transformed and partly upgraded by the community, but most energy input just passes through and out of the system as a heat sink. Conversely, material flows cycle within the system. Main flows concern nutrients such as carbon, nitrogen and phosphorus as well as water.

> An essential characteristic of life on Earth is the cycling within the system of chemical elements that are taken up from the environment, built into the tissues of living organisms, and then eventually released again into the environment – to become available for incorporation into new life. (Boyden, 2016, p. 23)

Metabolic dynamics are generally characterised by interactions between the following components (Boyden, 2016; Fischer-Kowalski and Haberl, 1993; Odum et al., 2004):

- producers (autotrophic organisms), or green plants that manufacture food from inorganic substances;
- consumers (heterotrophic organisms), which digest organic material;
- decomposers (also heterotrophic), like bacteria and fungi that take apart and absorb organic matter from plants or other organisms.

Green plants – or producers in this model – play a major role in accumulating energy by transforming sunlight into chemical energy through photosynthesis, thus providing for a great diversity of species. Ultimately this chemical energy is fed into the food chain to consumers and decomposers. Plants make use of the nutrients they need from the immediate environment: carbon from the atmosphere, oxygen from the atmosphere, and nitrogen and phosphorus taken from the soil and water (Boyden, 2016).

Ecosystems represent one of several systemic levels of organisation, starting with the intra-organic elements of cells, tissue, organs and organ systems. A group of organisms forms a population, and all populations within a given area form a community. The community and its non-living environment form an ecosystem. The worldwide sum of all ecosystems, the biosphere, is considered the highest level of organisation. While ecosystems as well as organisms are functionally open units, the biosphere is a closed, self-regulating system bound to the limits of Earth (see Figure 4 Borders between ecosystems are fluid and overlapping. In theory, a complete ecosystem includes an input and output environment with dimensions that depend on the system's size, metabolic intensity and balance (Odum et al., 2004). For instance, rain forests are considered relatively closed-cycle systems as they continuously recycle their own nutrients. In contrast, floodplains are considered flow systems because they depend on an external nutrient supply but contribute to the larger network by extracting nutrients and discharging outputs (Fischer-Kowalski and Haberl, 1993).

All of these organisational levels are based on living networks (Capra, 2015). It is the self-organising and self-generative character of nature that is not entirely understood yet and that inspires the urban metabolism debate. Zev Naveh emphasised the *autopoietic* character of ecosystems, meaning that

> systems on a relatively high organisational level that can renew, repair, and replicate themselves as networks of interrelated component-producing processes, in which the network is created and re-created in a flow of matter and energy. (Naveh, 2000, p. 359)

Haraway highlighted how the meaning of autopoietic systems implicates a form of central control. She argued that ecosystems should instead be described as sympoietic systems since production mechanisms are distributed among several components and are collective (Haraway, 2016).

3.1.2.2 Ecosystems of the technosphere

Human beings used to fit into the model of natural ecosystems as predator-type consumers because they were hunters and gatherers and low-tech/low-invasive farmers. After the Industrial Revolution, urban systems and their supply and disposal structures became technoecosystems (Odum et al., 2004), or landscapes of the technosphere (Naveh, 2000) that are dependent on natural ecosystems. Boyden distinguished between biometabolism and technometabolism, where the energy and material flows into, through and out of the human population result from technological processes (Boyden, 2016, p. 60). Baccini and Brunner used the term anthroposphere to describe humanity's sphere of life, which they understand as a complex technical system of energy, material and information flows that is part of the biosphere (Baccini and Brunner, 2012).

In ecology, the theoretical maximum population density that can be supported indefinitely in a certain ecosystem is called carrying capacity. Humans seem to have overcome these regulations. Via fossil energy sources, division of labour and global interconnectedness, the human population has seemingly detached itself from the immediate natural conditions (Haber, 2016). In technoecosystems, the concept of carrying capacity is not a static variable but describes the relationship between population development, the level of tapped resource potential and strategies and technologies to fully exploit these resources (Prytula, 2011). In the 19th century, German chemist Justus von Liebig argued that soil fertility decreases with every harvest unless extracted minerals are returned. He was critical of introducing sewage systems as he proposed recirculating excrement into agricultural production areas to close nutrient cycles. He feared the valuable resource of digestive residues would be diluted and lost. Liebig later invented chemical fertilisers, which represented a major step towards expanding the urban metabolism (Gandy, 2004; Prytula, 2011).

Urban systems are not self-generative as they do not efficiently produce and recycle materials. The urban metabolism extends into and depends on the 'original' natural ecosystems of the biosphere (Baccini and Brunner, 2012; Odum et al., 2004). While Odum described technoecosystems as 'competitive with and parasitic on natural ecosystems', he also stated that the heterotrophic character of cities is unproblematic as long as they are sufficiently connected to autotrophic systems for supply.

> If urban-industrial societies are to survive in a finite world, it is imperative that technoecosystems interface with natural life-support ecosystems in a more positive or mutualistic manner than is the case at present. (Odum et al., 2004, p. 71).

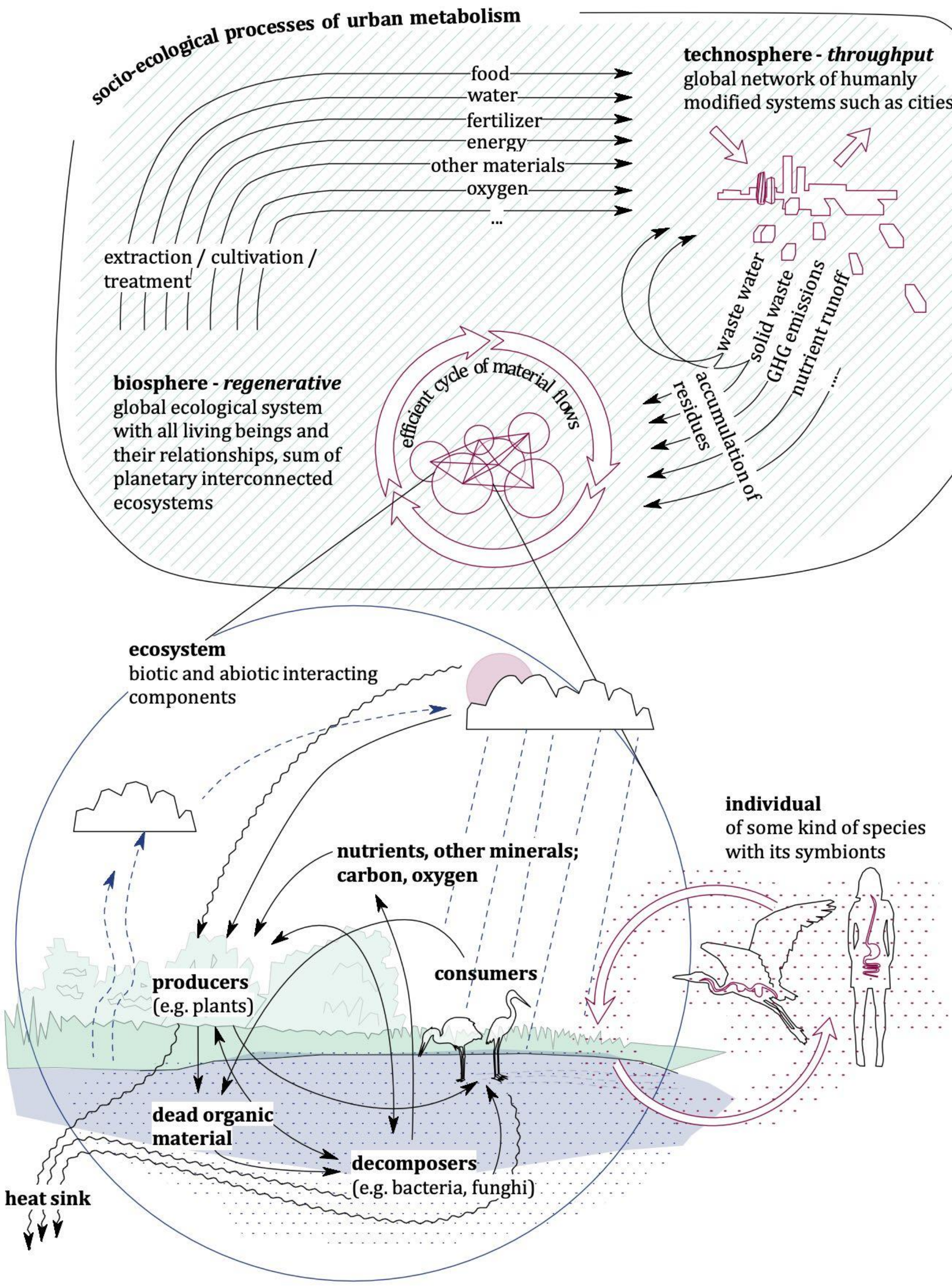

Figure 4 Contrary to the biosphere, the technosphere does not efficiently produce and recycle materials. Its metabolism extends into and depends on the biosphere

3.1.3 Interrelations in the urban metabolism

The scope of urban metabolism is complex and contains the interrelationships between natural systems and urban systems in the dimensions of space and time (Baccini and Brunner, 2012).

Fischer-Kowalski emphasised the differences between basal and advanced societal flow regimes (Fischer-Kowalski et al. 1997). Basal flows comprise all biological processes needed for human life, such as food intake. Advanced flows comprise all processes needed for any other social activity incorporating non-renewable resources such as fossil fuels or metals that usually do not occur in the biosphere's metabolism.

Prytula identified four dimensions of interaction in the urban metabolism: 1) physiological interactions, which include all energetic-material processes needed to construct and maintain urban systems; 2) spatial-temporal interactions, which include the supply and disposal relationships between urban systems and their service regions; 3) socio-economic interactions, which include relationships between the various actors that drive urban metabolism and physiological processes; 4) epistemological interactions, whereby urban systems are patterns of information that maintain and reproduce cultural behaviour such as traditions, values and production techniques (Prytula, 2011, p. 58).

Baccini and Brunner confirmed that cities are the most complex products of human invention, making the structuring and assessment of urban metabolism a great challenge. Metabolic processes follow natural laws. The establishment and management of these processes are determined by the cultural properties of a given society. Thus, Baccini and Brunner proposed structuring the assessment of an urban metabolism based on human activities:

1) to nourish – producing, consuming food, releasing wastes of digested residues;

2) to clean – human hygiene, maintain goods and environmental protection in terms of waste treatment and management;

3) to reside and work – constructing and maintaining buildings;

4) to transport and communicate – transportation of persons, goods, and information.

Nourishing and cleaning are driven by biological needs, while residing and working and transport are mainly characterised by socio-economic needs. Associated processes and flows can often be assigned to more than one activity (Baccini and Brunner, 2012, p. 81 et seqq.).

The weeklong workshop 'Towards an Integrated Perspective on Urban Metabolism' (see Figure 5) emphasised the driving forces of the social system based on certain activities (Dijst et al., 2018). Accordingly, flows and stocks of the urban metabolism 'are a part of and a consequence of activities that are undertaken within this environment' (Dijst et al., 2018, p. 192). The exchange process is a manifestation of needs and facilitators, including the constraints of individuals and communities, which are shaped by certain drivers from inside and outside the system. Activities are performed to fulfil needs shaped by cultural values. A constraint may be high costs, while a facilitating factor may be low costs. Drivers are considered to impact macro developments and comprise 'socio-cultural (e.g., values and norms), economic (e.g., growth and decline), political (e.g., power relations and policy aims), demographic (e.g., ageing and population decline), urbanisation, climate change and natural resources' (Dijst et al., 2018, p. 193). From this perspective, the authors underline the need for a multiscale analysis that includes concrete spaces such as a neighbourhood with specific spatial constellations as well as individual behaviour and choices. This analysis needs to reflect aggregated data of a larger scale, e.g. the city region, to better understand the relationship between the needs, activities, material flows and stocks.

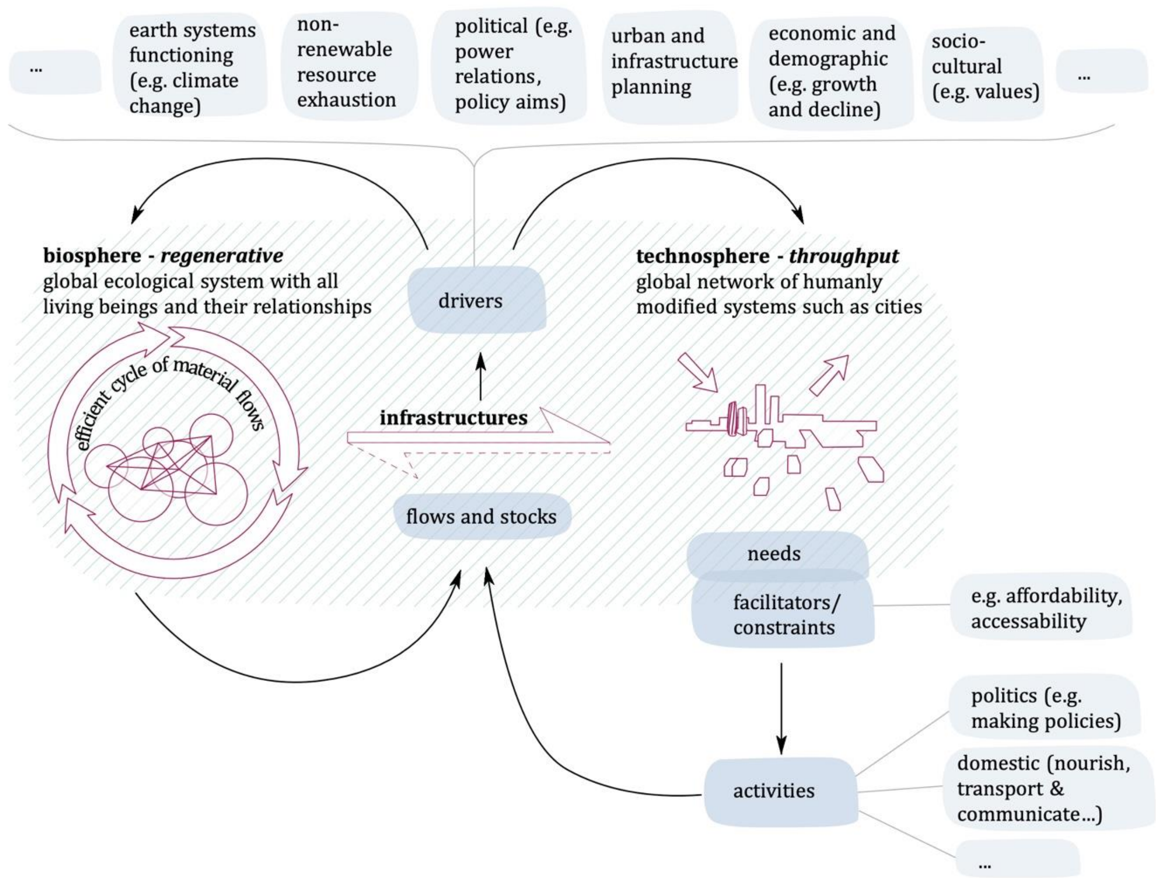

Figure 5 Interrelations of urban metabolism, adapted from Dijst et al. (2018, p. 192 Fig. 3)

Infrastructures play a central role in facilitating exchange processes. Thus, urban and infrastructure planning is a driving force and crucial field of action. In this context, the focus of a structuring approach could also be on the design of infrastructures. If urban metabolism was to function as well as the metabolism of a natural ecosystem,

> the wastes generated by resource consumption must be reused somehow to prevent them from accumulating and harming the internal and external environments that sustain the system. Research on urban metabolism therefore focuses on the sources and consumption of resources, and on their cycling within the system plus the emission, treatment, and recycling of wastes. (Zhang, 2013, p. 464)

This focus requires thinking more directly from the infrastructure perspective, including the supply infrastructure of water, energy and food; the disposal infrastructure of wastewater and solid waste; and near-natural and hybrid green or blue-green infrastructure elements that are closely interwoven with the urban system. In this sense, guiding questions to structure an urban metabolism analysis would be

- how does current and potential future infrastructure facilitate the flows within the city region?
- where are potential interlinkages that can be used to better exploit synergies between the infrastructure systems?

Box 2) Disambiguation of urban metabolism

Definition of urban metabolism

Metabolism is defined as all physical flows and stocks of energy and matter within and between the entities of a living system. The term originates from the Greek term for 'conversion' and was mainly used to describe physiological processes within an organism in the early 19th century. Later, metabolism also included material exchanges between organisms and their environment, such as ecosystems (Baccini and Brunner, 2012; Swyngedouw, 2006).

Urban metabolism is a framework for modelling complex urban systems' flows – of water, energy, food, people and so on – as if the city were an ecosystem. It can be used to analyse how urban areas function with regard to resource use, the underlying infrastructure and the relationship between human activities and the (natural) environment (Department of Urbanism at the Faculty of Architecture and the Built Environment, Delft University of Technology, 2018).

Development of the concept of urban metabolism

Conceptualisation and early forms

Karl Marx was the first to describe the metabolic processes of physical human labour and the extraction and processing of natural resources, and he introduced the German term Stoffwechsel (Marx and Engels, 1867). Robert Ezra Park analysed the city as an expression of humanity in general and specifically of social relations during urban growth. He coined the term 'social metabolism' to denote these dynamics (Park et al., 1925).

Abel Wolman's work significantly contributed to understanding of the system-wide impacts of consumption and waste generation within cities (Kennedy et al., 2011). His ground-breaking article 'The Metabolism of Cities' dealt with the establishment of water and sewage systems in the 19th century in the US. He described how 'metabolic requirements of a city can be defined as all the materials and commodities needed to sustain the city's inhabitants at home, at work and at play' and maintained that this cycle is not closed until waste has been removed or disposed of because the Earth is a closed ecological system (Wolman, 1965, p. 156).

In the 1960s, the metabolism concept gained popularity among Japanese architects as a response to rapid urbanisation. Self-proclaimed 'Metabolists' such as Noboru Kawazoe and Kisho Kurokawa designed flexibly expandable megastructures that can be rearranged or reconstructed in a metabolic cycle. However, apart from the construction and reconstruction process, other energy and material flows were neglected (in Prytula, 2011, pp. 49–52).

The famous publication Limits of Growth (see also Box 1) uses metabolic thinking. It is based on a prototype computer model of the world developed by Jay W. Foster. The model investigates five major trends: 'accelerating industrialization, rapid population growth, widespread malnutrition, depletion of non-renewable resources and a deteriorating environment' (Meadows et al., 1972, p. 21). The model seeks to reveal the interrelationships of these trends and their implications.

The discourse of urban metabolism was also shaped by research from the ecological perspective. In the book Fundamentals of Ecology, system ecologist Odum describes cities as urban-industrial technoecosystems that 'depend more and more on reconnecting the city to the life-supporting land and water bodies' (Odum et al., 2004, p. 411). The approach applies biophysical value theory to urban systems and is centred on solar energy equivalents as units (Kennedy et al., 2011).

Scholars have called to address the role of the social system in shaping the urban metabolism in the Anthropocene. Major planetary changes are a result of 'changes in the way that we choose to use a service or the way that services are offered to the consumer' (Dijst et al., 2018, p. 192). Moreover, 'socio-metabolic interactions' produce 'profoundly uneven socio-ecological conditions' (Swyngedouw, 2006, p. 114).

Progress through material flow analysis (MFA)

During the 1980s, the discourse on urban metabolism had slowed before the development of material flow analysis (MFA). MFA and substance flow analysis (SFA) are considered the basis for all methods of assessing urban metabolism. MFA is used to analyse flows and stocks of goods, meaning entities with economic value, while SFA analyses flows and stocks of substances, meaning chemical elements and compounds that are the basis of goods (Baccini and Brunner, 2012).

In 1990, Girardet, a pioneer of industrial ecology, analysed how urban metabolism is often linear and proposed a circular metabolic model instead (Girardet, 1990). In 1991, Baccini and Brunner published the book Metabolism of the Anthroposphere, and a second edition was released in 2012 (Baccini and Brunner, 2012). The Anthroposphere addresses the planetary dimension of global networks of urban systems and ecosystems. Based on emerging MFA tools, their work builds on metabolism studies in the 1970s and considers energy, water, material and nutrient flows.

Rapid progress in computer technology has enabled the development and use of models to simulate and evaluate metabolism. While Girardet's approach is based on a black box model with input-output accounting only, current research aims at modelling a network process for urban metabolism in which metabolic processes are abstracted as nodes and the flows between them are paths. These models analyse the interactions between the components (Zhang et al., 2015, p. 11252) and can also include the modelling of metabolic stages (anabolism, catabolism;[3] (Zhang, 2013, p. 465). An early application of network modelling is ecological network analysis (ENA) based on input-output techniques to simulate structural distribution of ecosystem components and relationships between trophic levels. The model was eventually extended by defining a matrix of flows which enabled tasks such as sensitivity analyses. ENA is mostly applied in research on natural systems but has also been applied to cities (Zhang, 2013, p. 468).

[3] Anabolism means the construction of elements requiring energy; catabolism means breaking down elements into smaller units releasing energy

Application examples

In the 20th century, urban metabolism studies were carried out in various cities, including Brussels (1970s), Tokyo (1970), Hong Kong (1971, 1997), Sydney (1970, 1990), Toronto (1987, 1999), Vienna (1990s), London (2000) and Cape Town (2000; (Kennedy et al., 2007).

With improved technological possibilities and increasingly pressing urban challenges, new studies are differentiating more with regard to the spatial level of observation, intentions and parameters (Zhang et al., 2015). More recent applications include an analysis of 'historical changes in the food and water supply systems of the New York City Metropolitan Area' based on methods such as net anthropogenic nitrogen input (NANI) calculations, which revealed the implications of food consumption on the environmental health of New York and its region (Swaney et al., 2012). Another study accounted for the urban material flows and stocks of the Lisbon Metropolitan Area for 28 material types (e.g., fuels, metals and cement as well as food in the form of agricultural and animal biomass) and 55 economic activity categories (e.g., agriculture, mining, transport). The analysis was based on MFA and created specific plugins to describe the material composition of goods, and the calculations are able to project obsolescence of materials and potentials for recovery in the future (Rosado et al., 2014). An analysis was made of solid waste flows and their travel distance for disposal for three cities in France (Rennes, Le Mans, Marne-La-Vallée) and found that patterns vary between cities and waste fraction, with textiles travelling to distant places such as Burkina Faso and Madagascar and construction and organic waste staying in the region (Durand et al., 2016). An urban metabolism analysis and strategy for Rotterdam was developed as part of the International Architecture Biennale Rotterdam (IABR) with the title URBAN BY NATURE in 2014. Flows include goods, people, waste, biota (movements of plants and animals), energy, food, freshwater, sand and clay, and air. The study has a strong spatial emphasis, using MFA and mappings at the scale of the city region and the larger catchment area of the Rhine (Gemeente Rotterdam et al., 2014).

Moreover, the idea of urban metabolism is reflected in national and international policies for transitioning to circular economies and better resource utilisation, such as the Dutch Vision Circular Agriculture 2030 (Ministry of Agriculture, Nature and Food Quality of the Netherlands, 2019); the interrelated strategies of the European Green Deal, such as the Circular Economy Action Plan first introduced in 2013 and updated in 2020 (European Commission, 2020a); and the Farm to Fork Strategy (European Commission, 2020b) (see also 3.1.4.1).

Outlook for further research and practice

In the past 10 to 15 years, urban metabolism research has been mainstreamed, and analytical assessment of energy and material flows has become a standard method for the investigation and explanation of urban supply and disposal processes, with numerous studies on different material flows (e.g., phosphorus, biomass in land use scenarios) on scales from the household or neighbourhood to regional or national systems (Prytula, 2019). Despite increased research, urban metabolism assessment and planning as part of urban development have not become standard. Sectoral assessments such as results from water and wastewater simulation are translated into strategies and measures, but planning decisions otherwise continue to be determined primarily by infrastructural, economic and other social parameters (e.g., housing needs or traffic planning). Operationalising urban metabolism as a control instrument for sustainable development of urban systems would require a systemic integration into municipal decision-making processes (Prytula, 2019).

Urban metabolism is still a developing field that requires further integration of different disciplines and scales to better understand urban ecosystems in terms of their ecological as well as their socio-economic interrelationships (Dijst et al., 2018). Moreover, there is a need to establish unified and standardised research to create consistent databases that better allow comparison between different case studies and regions and to better integrate the spatial sphere (e.g., geographic information systems [GIS]; (Zhang et al., 2015).

3.1.4 Guiding principles of optimised urban metabolism

3.1.4.1 Sustainability

Since it has come into widespread use, the term 'sustainability' has somewhat lost its persuasiveness. Tsing remarked that the usage of the term for the 'dream of passing a liveable Earth to future generations' makes her 'laugh and cry' at the same time since it covers up the 'destructive practices' of the past (Tsing, 2017, p. 51). Despite its mis- and over-usage, sustainability remains the key concept in dealing with the metabolic relations between urban and natural systems. A sustainable metabolism reflects the idea of these systems co-existing permanently based on balanced exchange processes (Broto et al., 2012; Kennedy et al., 2011). Existential human needs are satisfied without endangering the physiological conditions of our existence (United Nations General Assembly, 1987) (see Box 3).

> Shifting from managing natural resources one by one and treating the environment as an externality to stewardship of interdependent socio–ecological systems is a prerequisite for long-term human wellbeing. (Folke et al., 2011, p. 720)

Strategies for more sustainable development aim towards reducing energy and material flows while maintaining the population's quality of life, that is, ensuring basic human needs and well-being. Usage of materials and energy does not exceed the biosphere's capacity for regeneration and waste assimilation (United Nations General Assembly, 1987). Applied to sustainable city development, the biosphere's capacity is that of its hinterland, consisting of fragmented areas that are impossible to demarcate due to the global interconnectedness of planetary urbanism (Brenner, 2014b) (see 2.1.2). Hence, assessing the relationship between a city and its dispersed hinterland is the 'relative bar against which progress may be measured' (Kennedy et al., 2007, p. 44).

Strategies can be categorised as focussing on *increased efficiency, sufficiency* or *consistency*. *Sufficiency* strategies aim for reduced resource use through changes in consumption pattern. The abstention of consumption can be achieved through governmental incentives or education, or because resources are actually (locally) not available (which represents a constraint; see Figure 5). *Efficiency* strategies aim for better use of resources through improved technologies. In this way, energy and material turnover for the manufacture of a product or the provision of a service is reduced so that available resources can be conserved. *Consistency* strategies intend to transition from a throughput to a *circular economy* through increased resource effectiveness. Wastes are recycled, and regained resources are fed into new production processes as far as practicable (Prytula, 2011, pp. 31–33).

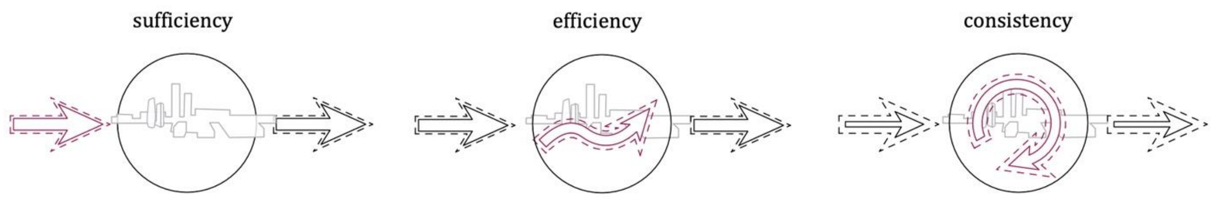

Figure 6 Sustainability strategies: sufficiency, efficiency and consistency, based on Prytula (2011)

Circular systems

Metabolic flows that used to be interdependent have become disconnected as infrastructure systems were built following the paradigm of a hygienic city in response to 19th-century sanitary challenges in the Global North's growing cities. Ever since that point, wastes tend to be managed as quickly as possible (Gandy, 2004; Wiskerke, 2015) (see 3.4.1.1). As a counter draft to the currently prevalent 'once-through' or linear systems, the principles of circular systems are inspired by natural ecosystems' functioning, which is an almost loss-free circulation of nutrients and minerals. To reach long-term viability and sustainability, cities need to recycle outputs back into the system, rendering them inputs once again (Broto et al., 2012). Thus, cities simulating natural ecosystems are 'healthy urban superorganisms' that are getting rid of metabolic '*disorders*' (Zhang, 2013, p. 463). The main disorder for urban metabolism is low efficiency in capturing metabolites (e.g., wastes or pollutants) for reuse or at least detoxification, which leads to resource depletion, pollution and ecological damage. Energy and materials can potentially be reused multiple times and for different purposes.

> The 'circular economy' is a new global economic paradigm that, looking beyond the current 'take, make, and dispose' mode, is designed to be restorative and regenerative and, relying on system-

> wide innovation, aims to redefine products and services to eliminate waste, while minimizing negative impacts. (Capodaglio, 2017, p. 2)

Depending on the goods, various strategies can be used to maintain the goods' material and economic value, such as recovery, downcycling or the energetic utilisation of the raw materials used (Prytula, 2011).

This paradigm shift has entered the policy level. The European Commission adopted a Circular Economy Action Plan in 2015, which boosted circular activities such as repairing, reusing and recycling and increased the use of recycled materials. The European Commission proclaims to inhabit a leadership role by 'designing and producing circular products and services and in better empowering consumers to adopt more sustainable lifestyles' (European Commission, 2019a, p. 10). An updated version of the Action Plan was published as part of the European Green Deal, with a section dedicated to 'Food, water and nutrients' as a key value chain for a sustainable circular economy (European Commission, 2020a). Notably, the recent Dutch Vision on Circular Agriculture 2030 also entails a paradigm shift from 'growth in production volumes and cost price reductions towards optimisation in resource use and food production in harmony with nature' (Ministry of Agriculture, Nature and Food Quality of the Netherlands, 2019, p. 2).

Approaches to tightening cycles

Assessing and finding possibilities for tightening resource cycles requires an understanding of the metabolic processes within the city. Initial research on urban metabolism was based on linear models that focused on sufficiency in terms of input and output, such as Abel Wolman's work (see Box 2). Knowledge of how to assess urban metabolic processes has since deepened through fast development in data handling and computer simulation. For example, Yan Zhang of the School of Environment, Beijing, introduced network processes instead of displaying the city as a black box model (Zhang, 2013). Systemic assessment through modelling also allows multi-perspective sensitivity to potential side effects of infrastructure planning beyond demand coverage and economic efficiency (Kropp, 2018). This kind of systemic thinking is inevitable because in a densely populated world with increasingly overlapping urban metabolism, trade-offs of resource utilisation can no longer be externalised to something conceptualised as 'outside' (Brenner, 2014b).

The following sections outline nutrient and water cycles as these are of particular relevance for designing PGI systems that align with other infrastructure sectors. Energy flows are not in the focus of this dissertation.

Nutrient cycles

Tightening the nutrient cycles requires minimisation of substance losses between urban food systems, water and wastewater, energy and waste management. In particular, the recycling of nitrogen and phosphorus is gaining relevance.

> A few years ago, flying from Rio de Janeiro to Sao Paulo I observed Rio's vast, brown sewage 'plume' oozing out into the sea. Similar images can be seen at coastal cities all over the world. This one-way traffic of nutrients – from farmland, via cities into the sea – is causing havoc to coastal waters across the planet. These plumes contain the nitrogen, potash and phosphate that should be used for growing the crops we eat. In addition, a substantial proportion of the artificial fertilisers now used on the world's farms also ends up polluting rivers and coastal waters. If we are to create sustainable cities, we need to look at the nutrient flows between cities and the countryside, and at the 'metabolism' of our cities. (Girardet, 2005, p. 35)

Assessments of Vienna's regional metabolism by Baccini and Brunner confirmed this observation. The study demonstrated that on top of over-application of fertilisers in agriculture, large fractions of nitrogen are released and lost by wastewater plants to receiving water bodies. Moreover, assessment of phosphor flows indicated that large amounts of nitrogen are lost due to transnational distortion of nutrient cycles. Animal feed to produce meat is often imported from distant regions where phosphorus is extracted from the soil through harvesting. Resulting phosphorus-containing waste from meat production is stored in the soil or released to surface waters. As phosphorus is a limited resource, efforts are then made to extract it from sewage sludge, either through separate collection or incineration and recovery from resulting ash (Baccini and Brunner, 2012).

To develop closed-loop designs at the nexus of water energy and food, a localised food system approach is seen as a 'critical element' (Skar et al., 2020, p. 9). The urban food system approach (see 3.2) aims to minimise food losses within its components by preventing food waste and optimising residual food waste streams through utilisation as animal feed, raw material for the industry or fertiliser through co-fermentation or composting (Wiskerke, 2015). In this sense, in urban agriculture, the productive spatial units of the urban food system have the ‘capacity to absorb urban waste’ (Smit et al., 2001b, p. 1) and thus inhabit a key role in tightening nutrient cycles.

Water cycles

Regarding water supply, more efficient use and recycling are applied, particularly in drought-prone regions. Recovery of water and diversification of sources such as greywater and rainwater for toilet flushing are gaining popularity (Gorgich et al., 2020). More sustainable technologies have also emerged in the water system sector, driven by general process improvements and the need to recycle resources to accommodate a growing population and sustainable development goals. Microbial structures in activated sludge are now better understood. Innovative engineering allows for intensification of separation processes through membrane separation. Decentralised wastewater treatment plants with membrane technology can reduce freshwater consumption; energy can be generated from biogas produced from the sludge, and nutrients such as phosphate can be recovered; and cellulose fibres, bioplastics and biopolymers can be produced (Binz and Truffer, 2009; van Loosdrecht and Brdjanovic, 2014).

Moreover, there is a growing interest in assessing the urban water system's entire metabolism, which comprises the supply of drinking water; stormwater and wastewater collection; and the environmental impacts of the system, such as containment discharge and emissions. The integrated assessment is enabled by technological progress in data handling and modelling. Simulation of strategic planning based on sustainability criteria reveals the benefits of the integrated planning of the entire urban water system and measures for optimised resource management, such as rainwater harvesting and greywater recycling schemes (Behzadian and Kapelan, 2015).

3.1.4.2 Equity

Analysing, reviewing and potentially optimising urban metabolism requires consideration of social interrelations and questions of equity. Researchers have made connections between urban metabolism research and the environmental justice debate to address how uneven distribution of resources impacts people in relation to their locality and social status. Achieving environmental justice in urban metabolism goes beyond providing overall sufficient resource quantities to recognise the capabilities of different social groups and individuals (Dijst et al., 2018, pp. 196–197).

Capability is a theoretical framework also used by the yearly Human Development Report of the United Nations Development Programme (UNDP), which widened the former basic human needs framework. Instead of defining and fulfilling basic human needs such as food, shelter, clothing, health and education (The Cocoyoc Declaration, 1975), human development strives to widen people’s choices and capabilities to live a long and healthy life. The Human Development Report was greatly influenced by Amaryta Sen's work who emphasised the freedom of choice in a life of individual value (Rudra, 2009; Sen, 1992). Human development emphasises that economic actions are means to human needs and not ends themselves (Jolly et al., 2009). It ‘is about expanding the richness of human life, rather than simply the richness of the economy in which human beings live’ (United Nations Development Programme, 2020).

Dijst et. al proposed equity as a central planning principle for urban metabolism research and planning, emphasising aspects of fair distribution of resources, the capabilities of people and the responsibilities that result from these capabilities. In this sense, equity and sustainability are intertwined as people are only able to carry environmental responsibility in socially just systems (Dijst et al., 2018, p. 197).

Box 3) Disambiguation of Sustainability

Definition of sustainability

Sustainability outlines the idea of urban and natural systems co-existing permanently through balanced exchange processes. The central goal of sustainable development is to satisfy existential human needs on a global scale and to enable prosperity without endangering the physiological conditions of life on Earth (Global Footprint Network, 2020; United Nations General Assembly, 1987). The science of sustainability considers the complex relationship between nature and humankind based on a holistic approach (Lin et al., 2018). Sustaining the web of life requires systemic solutions to interrelated problems. In the view of many scholars, systemic changes are needed, such as reshaping economic globalisation and corporations (Capra, 2015; Fritzsche, 2020).

Development of the concept of sustainability

The origin of the term 'sustainability' can be attributed to German forestry expert Hans Carl von Carlowitz and his publication Sylvicultura Oeconomica in 1713, which promoted a concept of permanent resource management as a response to the impending shortage of wood. Von Carlowitz argued that no more wood should be extracted from a forest than will grow back over a defined period of time (in Prytula, 2011; von Carlowitz, 1713). The concept of sustainability became mainstream in the 1980s, and environmental, economic, and social aspects were acknowledged as the three interdependent sustainability pillars, also known as the *triple bottom line* (Purvis et al., 2019).

Sustainability was first formulated as a global political goal in the United Nations's Brundtland Report in 1987. The report defines sustainabiliy as a development 'that meets the needs of the present without compromising the ability of future generations to meet their own needs' (United Nations General Assembly, 1987). In light of the global crises in the 1980s, the Brundtland Report attempted to take a holistic approach across different sectors (agriculture, energy etc.) and the three domains of environmental, economic, and social pillars, described as 'broad areas of concern'. However, the report still singles out the economic domain on the assumption that ecology and economy are historically separate spheres (though they never were, as per Section 2.4) and that social development follows economic development, which leads to the conclusion that economic growth is a key solution (James and Magee, 2016).

This unbalanced weighing is also due to the underlying framework of the triple bottom line. Recent critics have noted how economics tends to be seen as the dominant domain, while ecology is an external field. The more recent framework of the UN, such as the Sustainable Development Goals (SDGs) and UN-Habitat's New Urban Agenda (the operational guidance for cities in acting sustainably), intentionally avoid the structure of the triple bottom line by enumerating commitments. However, the SDGs still define sustainable development in terms of economic outcomes, and the New Urban Agenda can be read as separating the economic from the social and the environmental (James and Magee, 2016). The latest UN Global Sustainable Development Report strives to address the shortcomings of the triple bottom line by adopting a systemic approach to the SDGs and explicitly considering their links, co-benefits and trade-offs (Independent Group of Scientists appointed by the Secretary-General, 2019).

Since the triple bottom line lacks a well-founded theoretical framework and has been criticised (Purvis et al., 2019), an alternative approach, the so-called Circles of Sustainability, was developed in 2017. It was created through a long-term collaboration of several institutions and programmes, with the UN Global Compact Cities Programme foremost among these. The research outcome is a more nuanced conceptual and technology-supported framework with practical guiding tools for city planning. It builds on the efforts of the triple bottom line concept to integrate the domains and shift the focus from economic development alone, but it differs in terms of structure (James and Magee, 2016). The concept promotes the practical use of four different circles, each meant for a different stage of urban development: profile, process, engagement and knowledge. The profile circle serves as an analytical tool to understand a chosen region's strengths and weaknesses and to determine efforts towards sustainable development. Its diagram consists of a circle divided by four quadrants representing the domains of economics, ecology, politics and culture, all seen as social domains. The natural is defined as an infinite extension of time/space that exceeds human social engagement and is depicted as a surrounding open line. Ecology is defined as 'practices, discourses, and material expressions that occur across the intersection between the social and the natural realms, including the important dimension of human engagement with and within nature, ranging from the built-environment to the 'wilderness'' (Circles of Social Life project., 2020).

A metric for 'unsustainability' is the framework of the ecological footprint, which accounts for the use of bioproductive land and associated resources on the global level, as developed by Wackernagel (Wackernagel et al., 1999). The reporting, updating and refining of calculation methodologies has been carried out by the Global Footprint Network NGO since 2003. Biocapacity is measured in land use and yield of cropland, grazing land, fishing grounds, forests and built-up land. Carbon footprints are calculated based on fugitive and industrial emissions as well as the sequestration capacities of ecosystems. According to this framework, total ecological overshoot began in the 1970s and exceeded biocapacity by 69.6% in 2014 (Lin et al., 2018).

The so-called Global Sustainable Development Quadrant provides a framework for the national level, which serves to give a comparative overview of the development of different countries.

3.2 Urban food systems

An urban food system 'encompasses the different modes of urban food provisioning, in other words, the different ways in which locations where food eaten in cities is produced, processed, distributed and sold' (Wiskerke, 2015, p. 5). Urban food systems are shaped by social drivers such as politics, demographics, economics, science and technologies as well as ecological drivers such as conditions and changes of land cover, soil, climate, nutrients and water cycling ((Ericksen, 2008).

This dissertation focusses on the role of urban food systems as part of the urban infrastructure and urban metabolism. More specifically, it looks at the physical appearance of urban food systems' productive units that are part of the city green space network in the form of urban agriculture.

3.2.1 Conception of urban food systems

> The variety and complexity of the conditions shaping current and future urban food systems, combined with the interdependency of these conditions, indicate that it is an enormous challenge to create resilient urban food systems. (Wiskerke, 2015, p. 15)

These conditions must be addressed comprehensively in a systemic way that acknowledges that the system's entities influence each other and lead to emerging properties (Ericksen, 2008; Lang, 2010). The literature on the system theory of food systems has increased since the 1990s. A study from 1998 documented a multitude of existing food conceptualisations, but only a few of these were based on systematic frameworks that considered the full scope of food systems at the time (Sobal et al., 1998).

The notion of a 'system' intends to address the complexity and interaction between mutually dependent and interacting social and ecological components (Ericksen, 2008; Lang, 2010). From the system theory viewpoint, food systems are

> the set of operations and processes involved in transforming raw materials into foods and transforming nutrients into health outcomes, all of which functions as a system within biophysical and sociocultural contexts. (Sobal et al., 1998, p. 853)

The description of processes 'from land to mouth' (Kneen, 1993, p. 8) or from 'field to fork' (Jennings et al., 2015, p. 26) is a key feature within the discourse of urban food systems. The sequence of process steps is often conceptualised as a value chain (Cabannes and Marocchino, 2018). Classification of these process steps varies in literature. Research at the Technische Universität Berlin conceptualised five major components of urban food systems, with an emphasis on their systemic as well as their spatial dimension (see 3.2.2). This classification shares similarities with that of Dahlberg, first defined in 1993, which comprises 'production, processing, distribution, access, use [i.e., consumption], recycling and composting' (Dahlberg, 2002).

After a long absence in the 20th century, food is now back on the urban agenda (see Box 4) and is considered part of urban infrastructure (Kasper et al., 2017). Initial motivation to urban food system planning did not lie in increasing awareness of negative environmental impacts but in the pressing challenge of existing and newly emerging forms of malnutrition. Disruptions in the food supply in the Global South as well as a rapid increase in diet-related health risks in industrialised and developing countries (see 2.3.3) raised calls to ensure 'food security' and 'food sovereignty' (Timmermann and Félix, 2016). Food planning mostly intends to ensure access to high quality nutrition.

Theory and practice have simultaneously shaped new cultures of food systems. Conceptualising food systems and grassroots activities has induced a myriad of novel partnerships, space production modes and participation culture. Scientists and activists assess, formalise, or initiate divergent forms of urban agriculture (Lovell, 2010). The availability of fresh produce for consumers and encouraging close relationships between consumers and producers through food hubs, farmer markets, or participative farming have gained traction (Barthel et al., 2016b; Blay-Palmer et al., 2015; Morgan and Rachel Santo, 2018; Wiskerke, 2015). The Association of European Schools of Planning (AESOP) acknowledged the role of food in the city as a compelling challenge of the 21st century and started a special working group on sustainable food planning in 2009, with annual meetings that attract between 80 and 100 participants, including academics, policymakers and practitioners. Food system planning and the integration of urban agriculture into the city's green space system are now prominently endorsed by international organisations such as UN-Habitat and the Milan Urban Food Policy Pact, which has been signed by 209 cities (see Box 4).

3.2.1 Urban food systems as infrastructure and their role in urban metabolism

Urban food systems represent a sphere of the urban metabolism that is not only a hybrid between urban and natural systems but that is also interconnected with other infrastructure systems. There are strong linkages with the urban water cycle, including stormwater, wastewater and water supply management. Various processes of the urban food system require water supply during irrigation or processing. Agricultural production units are part of green infrastructure and share the mechanisms of balancing water cycles through soil filtration, groundwater recharge and evapotranspiration. Urban food systems transform foodstuff into organic matter and accumulate packaging and organic residues, which connects them to the wastewater and solid waste infrastructure. Energy is required during the cultivation of crops, husbandry of livestock, cooling or heating of produce and food preparation. Agricultural areas for food production compete with biofuels. Metabolic processes within the urban food system are potential energy sources, such as the energetic use of biogas.

Due to their all-encompassing nature, the way food systems are organised substantially influences global change in the Anthropocene (see 2.3.2). It has been claimed that 'Feeding cities arguably has a greater social and physical impact on us and our planet than anything else we do' (Steel, 2008; cited in Wiskerke, 2015). Food is not only fundamental to human existence, food systems can also be considered a vehicle for understanding social-ecological, cultural and political interrelations and identifying solutions for more sustainable resource exchanges with natural systems (Moragues-Faus and Morgan, 2015).

> An emerging research and policy agenda essential to integrating food into urban planning focuses on better connecting food as an urban sub-system to cities as urban metabolism, and especially to waste, water, energy and transport. Much more needs to be done to turn this knowledge into planning practice, and 'integrating food system planning into urban metabolism' will remain a challenge for the years to come (Cabannes and Marocchino, 2018, p. 55)

3.2.2 Components of the urban food system

All definitions of the urban food system are based on the description of process components (see 3.2.1). The following sub-sections classify five major components and their systemic and spatial dimensions (see also Kasper et al., 2017). Spatial manifestation is integral to assessing the system's relation to urban development and serves to operationalise food system planning. The classification of process components aims at structuring and localising resource flows, identifying and generating synergies between other resource flows of the urban metabolism, and addressing and localising stakeholders' roles. The following sub-sections therefore define the five components, their relevance in food systems and their relation to spatial planning.

3.2.2.1 Production

Production describes the transformation of resources into agricultural products, namely crops and livestock. Besides the essential resource of land, input is required in the form of seeds, irrigation, fertiliser, and also labour (e.g. soil preparation, harvesting). Spatial manifestation ranges from soil-bound large-scale agricultural areas to small-scale sites within the urban structure, such as rooftop gardens that may be soilless (e.g., hydroponics).

On a global scale, it is often claimed that population growth requires an increase of agricultural production. The Food and Agriculture Organization of the United Nations (FAO) estimates that 50% more food will be needed by 2050 (FAO, 2017b). Others claim that achieving food security is a question of equitable distribution (Jennings et al., 2015). Indeed, land is a limited resource, and agriculture is already in competition with urbanisation and the production of biofuels (see 2.3.2). Turnover of land for agriculture is mostly carried out through deforestation and intense losses in biodiversity (see 2.3.3). A third of agricultural land is degraded due to overexploitation and unsustainable use. Globally, production is characterised by a shift towards large-scale, capital-intensive, and export-orientated agriculture and away from small-scale, labour-intensive farms (FAO, 2017b).

As the lens of urban metabolism emphasises, cities are a process of metabolic flows between ecosystems of the technosphere and ecosystems of the biosphere (3.1.1). Food items consumed within an urban food system may have been produced inside the city region or anywhere on the planet – a complexity that Han Wiskerke conceptualised as the hybridity of global-local food systems (Cabannes and Marocchino, 2018; Wiskerke, 2015). Aiming at a more sustainable urban metabolism anticipates assessing the potential of productive areas within the region to stimulate links and the exploitation of synergies with the dense urban metabolism and to reduce energy use for long-distance food logistics. For instance, New York City's policy framework for its urban food system takes into account a perimeter of 400 km (Quinn, 2010).

Production is most relevant for physical food system planning, including urban and landscape planning. When considering land use interests, the importance of regional agricultural land and productive units within the city structure – that is, urban agriculture – must be understood and given sufficient consideration.

3.2.2.2 Processing

Processing refers to the transformation of agricultural products. Some forms of processing are needed to render food edible, and processing can contribute to food availability through seasonal harvest gaps. However, some forms of processing can also lower nutritional quality (Global Panel on Agriculture and Food Systems for Nutrition, 2016). The latest food research highlights the relevance of the processing degree because the increased availability and marketing of ultra-processed, ready-made food correlates with the obesity pandemic and global public health crisis (see 2.3.3). Monteiro et al. claimed that food processing is the 'shaping force of the global food system, and the main determinant of the nature of diets and related states of health and well-being' (Monteiro et al., 2012, p. 1). According to the international NOVA classification, food groups in dietary guidelines should be classified according to their degree of processing instead of nutrients because of the stronger correlation between the intake of processed food and the occurrence of obesity. The classification comprises 1) unprocessed or minimally processed whole foods of plant or animal origin and foods that are not significantly altered through washing, peeling, refrigerating or freezing; 2) culinary ingredients such as plant oils or pasta derived from pressing, milling and crushing of constituents of foods like fats, flours or starches; 3) food products that are substantially altered or consist of formulations made from industrial ingredients and with a low share of whole foods (Monteiro et al., 2012).

Regarding the spatial dimension of the component processing, two aspects need to be considered. First, unprocessed or minimally processed food forms the basis for a healthy diet. These food items perish quickly, and the preservation efforts to make them endure longer transport distances are energy-intensive. In this sense, the nearby agricultural region of an urban food system plays a major role in supplying potentially healthy perishable foods such as vegetables and fruits. Second, food processing facilities generate added value. It is beneficial if they are located in the vicinity of small-scale farmers to counterbalance the current shift in favour of large-scale, export-led agricultural production (De Schutter, 2014).

3.2.2.3 Distribution/access

Distribution/access comprises the transport of raw and processed food products to consumers through different networks ranging from large-scale logistics through wholesale and retail infrastructure to smaller trading networks or even direct sales at production sites. Spatial manifestation includes wholesale market infrastructure (business to business) and access points for consumers (business to consumer), ranging from centrally managed large supermarkets to local wet/fresh/farmers' markets with individual merchants to smaller shops and kiosks or street markets and mobile vendors.

The endorsement of regional food system approaches and urban agriculture is often justified by reducing transport expenditure – as so-called 'food miles' are constantly increasing, resulting from intensifying global interconnectedness and globalisation of the food system (Lang and Heasman, 2004) (see 2.1.2). As laid out in Section 2.3.2, urban food systems are a significant source of greenhouse gas emissions. Many factors throughout the food system must be taken into account when assessing the cause of emissions, some of which are region-specific. For example, the climatic-seasonal conditions of a location can result in comparably high energy expenditure for production that exceeds transport-related emissions. For example, tomatoes grown in Dutch greenhouses emitted 16 times the amount of greenhouse gases compared to Spanish open-field tomatoes according to a study from 1997. Even after adding transport-emissions for the route between Spain and the Netherlands, the production and distribution of Spanish tomatoes only emitted a fifth of the gases of Dutch produce (Wascher and Jeurissen, 2017). In a more temperate climate, a 2015 study from Seoul, South Korea, found that the implementation of urban agriculture would reduce annual CO_2 emissions by 11.67 million kg, which is equivalent to the amount that can be absorbed by a 20 km^2 pine forest that is 20 years old (Lee et al., 2015). However, other researchers argue that regardless of location, diet styles and a high share of emission-intensive meat and dairy are far more relevant than transportation in general (Barthel et al., 2016a); this complexity underlines the importance of systemically considering the urban metabolism (see 3.1).

Globally, the share of processed food distributed through supermarkets is steadily increasing, while fresh food is continuously sold in local markets and other more decentralised retail structures, with hardly any increase of channelling through supermarkets between 2006 and 2014. It is believed that supermarkets, with their more complex and longer supply chains, have to factotr in energy-intensive cooling of perishables. Thus, local markets can often operate in a cost-competitive manner (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

Contrary to what would be expected against the background of continuing malnutrition, there is enough food for everyone; it is just not distributed sufficiently. It is estimated that the redistribution of only 1% of global food production would serve the global population (Jennings et al., 2015). Hence, *'the right to food*', meaning having physical and economic access to sufficient, adequate, and culturally accepted food (Committee on Economic, Social and Cultural Rights, 1999), is the a key postulation.

Physical food system planning in urban areas needs to recognise that 'food environments', or the food available to residents in their everyday life, have a strong influence on diet quality (Global Panel on Agriculture and Food Systems for Nutrition, 2016). The availability and accessibility of food that 'as a whole contains a mix of nutrients for physical and mental growth, development and maintenance, and physical activity that are in compliance with human physiological needs at all stages throughout the life cycle and according to gender and occupation' (Committee on Economic, Social and Cultural Rights, 1999 Article 9) must be key in food planning. The link between diverse dietary options and well-being applies to the local level in the urban environment. A case study from New York observed a correlation between a lack of access points for fresh produce and the occurrence of obesity in neighbourhoods. The problem was then tackled by installing fresh food carts (Quinn, 2010).

3.2.2.4 Consumption

Consumption refers to the preparation and consumption of food within private households, at restaurants or in public canteens. As laid out, persisting undernutrition and the increase in obesity can be considered a negative consequence of the state of urban food systems. Supply follows consumer demand, which is characterised by an increased desire for resource-intensive meat and dairy at the expense of equitable and sustainable development (Jennings et al., 2015) (see also 2.3.2). Demand reflects consumers' purchasing power and their awareness of their role in shaping the urban metabolism. To the extent of providing choices, diets can be seen as an indicator for the urban food system's functioning in terms of distribution/access.

The World Health Organisation and the Food and Agriculture Organisation have recently published guiding principles for sustainable and healthy diets to combat globally worsening forms of malnutrition as well as unsustainable agricultural practices. Nutrition ideally includes wholegrains, legumes, nuts and an abundance and variety of fruits and vegetables, and it can include moderate amounts of eggs, dairy, poultry and fish. Red meat should only be consumed in small amounts. Another explicit recommendation is an intake of 400 g of fruits and vegetables a day (FAO and WHO, 2019).

Food system planning ultimately aims to provide dietary choices that are adequate in terms of nutrition and cultural values as well as sustainable for the present and future (Committee on Economic, Social and Cultural Rights, 1999). Market regulation can be carried out through tax incentives in favour of healthy and sustainable products. Moreover, public canteens in schools, universities or administrations represent a major tool for installing and maintaining long-term relationships between producers, processors and consumers. Policy requirements can also be implemented, such as what percentage of meals served should come from agroecological farming.

3.2.2.5 Disposal/Valorisation

During all the aforementioned processes, losses occur. Through the disposal/valorisation process, the accumulated residues can be valorised and fed back into the agricultural production cycle or used for energy purposes. Spatially, these processes are directly linked to the food system components and connect to the infrastructure of solid waste and wastewater management, ranging from sewage networks, road-based collection infrastructure and nodes of disposal or valorisation such as landfills or different types of composting sites.

Food system planning aims at reducing losses wherever possible and reasonable. By identifying and managing interlinkages with related infrastructure sectors, residues are valorised.

3.2.3 Change in urban food systems

Despite the standardising forces of globalisation, urban food systems are always context-specific and highly variable. Food flows that concentrate in urban areas and manifest urban food systems are partly shaped by the socio-ecological traits of the region. Moreover, globalisation affects urban food systems to varying extents and has been slower in the Global South.

The Global South's food systems are often still characterised by a greater number of actors within all process components and a greater degree of local and regional production, particularly regarding perishable produce such as vegetables and fruit. There is a higher prevalence of small-scale producers with a higher degree of food production for their own food supply (Samberg et al., 2016). Generally, the local diet is characterised by a high share of staple crops and minor consumption of meat and dairy. Food production and logistics are more decentralised and often less energy- and technology-intensive. Typically, food losses occur more often during production, processing and distribution due to greater vulnerability to crop failure and storage difficulties, such as a lack of cooling. Comparably less food waste occurs in the process of consumption. Produce of the region is traded at a limited number of wholesale or local wet markets, with the informal sector of street vendors playing an important role in the distribution and accessibility of food within the city (Jennings et al., 2015).

More globalised food systems in industrialised countries have shifted towards large-scale, capital-intensive, and export-orientated agriculture, moving away from small-scale, labour-intensive farms and becoming dominated by national and international food production (FAO, 2017b; Lowder et al., 2016). Agricultural products are often sold to large retailers or processing companies through more complex, specialised food supply chains. Connections between urban consumers and regional producers are weaker as food chains stretch over long distances. Even perishable goods are obtained from distant regions through the energy-intensive logistics of larger supermarket chains that offer food at low prices based on powerful bargaining positions and economies of scale. The local diet is characterised by a higher share of processed and ultra-processed foods. More packaging wastes occur. Food losses occur more during the stage of consumption (Global Panel on Agriculture and Food Systems for Nutrition, 2016; Jennings et al., 2015).

Negative trade-offs of these changes – namely overexploitation and expansion of agricultural land and increasing malnutrition – have echoed in the need for food system planning.

Box 4) Disambiguation urban food system

Definition of urban food system

The urban food system stands for a conceptual framework to assess different modes of urban food provisioning, which consists of the systemic components of production, processing, distribution/access, consumption and disposal/valorisation of food wastes. Food that is consumed in a city can be produced and processed anywhere on the globe. The emerging approach of City Region Food Systems specifically assesses the potential of food production within the region by operationalising urban-rural linkages (see 4.4.2).

Development of the urban food system concept

Temporary absence in urban planning

The physical planning of urban food systems was absent during major phases of urban growth in industrialised countries. It is often claimed that the approach of urban food system planning only emerged at the beginning of the 21st century after food was identified as a ‘stranger to the planning field’ by Pothukuchi and Kaufman. Their literature review of the physical planning in urban design, land use, environmental, and infrastructure planning, economic development and so forth revealed that none included planning for food systems. Moreover, none of the major US planning journals nor any US planning agencies dealt with food systems. This absence is linked with shortcomings in urban planning. Key aspects of the food systems (e.g., land use management of productive areas, location of access points such as grocery stores) were not strategically planned or were planned without a full understanding of their relevance in the network of supply chains (Pothukuchi and Kaufman, 2000).

From today’s perspective, there were some approaches to food system planning in the 19th and early 20th centuries that could be considered food system planning as laid out in the following.

Forms of food system planning in the 19th and early 20th centuries

Essential aspects of food planning were integral to the first generation of professional planners in the era of urban growth in European and American cities in the 19th century (Donofrio, 2007; Vitiello and Brinkley, 2014). Several approaches that are considered forerunners of green infrastructure planning (see Box 5) can also be considered initial forms of holistic food planning. The relevance of agriculture in supplying food to the local community was a great concern for planners at the time. In the US, Frederick Law Olmsted integrated animal pastures and dairies into city parks to support maintenance and improve food security by provisioning milk to children of low-income households (Vitiello and Brinkley, 2014).

In Great Britain, Ebenezer Howard’s vision of the Garden City considered the whole metabolism of food systems, from production to the cycling of waste as fertiliser. He was concerned with value chains and saw local food production in relation to the availability of food from slowly globalising markets, noting that the gardens ‘are hardly likely to supply them with tea, with coffee, with spices, with tropical fruits or with sugar’ (Howard, 1902, p. 33; cited in Vitiello and Brinkley, 2014).

Another striking example is New York City's food system study from 1912, which explored questions on the origin of consumed food and the share of locally produced food as well as distribution issues. Main conclusions were that New York City depends on a global food network and that distribution lacked planning because the trading of food within the city through middlemen resulted in disproportionally high food prices. The study proposed to treat food as a public service like the water supply and sanitation and to organise food systems with the same rational efficiency. Shortly after this study, with the rise of regional planning in the 1920s, planners began to emphasise the interdependence of cities and their regions. Preservation of farmland gained relevance and marked the beginning of holistic food system assessment. The Regional Planning Association of America envisioned cities closely linked with their regions, defined as a geographic area with a certain unity of climate, soil, vegetation, industry and culture that is not necessarily congruent with administrative boundaries. They criticised regions of production as decoupled from places of processing or consumption and proposed the development of green belts of forests, parks and farmland. These ambitious visions lacked implementation as planning tools such as zoning did not exist at the time (Donofrio, 2007).

There are several reasons why food planning and agriculture diminished in the 20th century. First of all, urban and rural spheres had long been conceived of as static opponents (Giseke et al., 2015b; Wiskerke, 2015). Agriculture was more and more regulated out of cities and suburbs and subsequently was also neglected in planner's visions and people's experience of urbanity (Vitiello and Brinkley, 2014). This issue is also reflected in Pothukuchi and Kaufman's survey, where planners in the 1990s perceived food to fall into the domain of rural policy-making and did not consider it an urban issue (Pothukuchi and Kaufman, 2000). Another reason is the industrialisation of the food system through the rise of big business in farming, processing, and retail, which 'helped render city planners seemingly obsolete in the food system' (Vitiello and Brinkley, 2014, p. 13). The development and structuring of food systems were increasingly dominated by private companies and their logistic systems as well as a range of dispersed administrative bodies ranging from agriculture, rural development and trade.

Pioneers of Food Policies

A few cities adopted food policies on the city level in the 1990s, which paved the way for an integrated approach to food in many areas of planning and urban life early on. Belo Horizonte in Brazil was pioneering with its food policy titled Citizenship Action Against Hunger, Poverty and for Life in 1993. Today the three pillars of the strategy comprise a direct supply of food through canteens and food banks, market regulation and strengthening of urban agriculture based on agroecology (futurepolicy.org, 2019). Belo Horizonte has successfully reduced malnutrition and became a role model for Brazil's national Zero Hunger campaign (Wiskerke, 2015).

Similarly, Toronto is exemplary for the evolution of urban food policies. The Toronto Food Policy Council was established in 1991 as a citizen-based subcommittee of the Health Department and contributed to many policies and activities. Outstanding milestones were the development of the Toronto Food Charter in 2000 and the integration of food issues into the overarching framework of the 2002 Official Plan (Jennings et al., 2015). While the focus initially lay on food security, subsequent activities such as the Toronto Food Strategy (2010) and the Urban Agriculture Action Plan (2012) had a wider scope, striving for a '*healthy and sustainable food system for Toronto'* and emphasising implementation (Toronto Food Policy Council, 2020).

Reappearance of food system planning in the 21st century

After Pothukuchi and Kaufman's eye-opening article in 2000, critical examination of the role of urban food systems increased significantly. In fact, 'food is no longer a stranger to planning practice', as a survey from 2014 in the US determined (Raja et al., 2018). Food is back on the urban agenda, as illustrated by the Milan Urban Food Policy Act or the emphasis on food in the UN New Urban Agenda. Environmental and health concerns are similar to the discourse 100 years ago, though the world faces greater globalisation, increased imbalance of natural systems and the spread of 'civilization diseases' such as obesity and diabetes (Jennings et al., 2015; Vitiello and Brinkley, 2014).

Food system planning is largely carried out on the sub-national and municipal level, with small towns and city regions filling in gaps left by the inaction of national and international institutions (Morgan and Rachel Santo, 2018). In many cities, various strategic plans deal with aspects of urban food systems by promoting productive spaces in the city and reassessing modes of distribution and acquisition. The emergence of comprehensive food system policies is considered one of the fastest-growing social movements in the Global North. In addition to the pioneers of Belo Horizonte and Toronto, examples of food system planning include the London Food Strategy (first established in 2006, regularly updated; (London Authority, 2018), the comprehensive Food Works Vision to improve New York City's food system in 2010 (Quinn, 2010), and Berlin's Ernährungsstrategie food strategy (Senatsverwaltung Berlin, 2019).

These food policies have often been initiated or at least evaluated and influenced by local food policy groups (e.g., food councils) that consist of stakeholders from the government; civil society; and the private sector, such as farmers. The emergence of these groups is well documented in the Global North, with a concentration in North America (325), the UK (51) and other European countries. These groups have started to connect via platforms such as the Food Policy Network for North America or the Milan Food Policy Pact, as well as the FAO Food-for-Cities initiatives on a global level. A multitude of organisations endorse municipal food system planning, including the American Planning Association Food Systems Interest Group, the CITYFOOD Initiative and the EAT Forum in Europe (Morgan and Rachel Santo, 2018).

A literature search did not yield many results regarding systemic food system planning in Asia or the Global South. However, on a global scale, Asian cities are considered to have the most diverse and intense urban agriculture practices, as examples from China, Japan, Indonesia, the Philippines, Nepal, Pakistan, Singapore, Thailand and

Vietnam illustrate. Despite rapid urbanisation, many Asian cities have conserved their long tradition of urban food production, and practitioners benefit from relatively supportive municipal and national governments (Quan et al., 2013; Smit et al., 2001c).

A newly well-documented case is that of Bangkok. While there is no overarching single food system policy, many formal and informal activities have successfully been developed that address the multiple scales of the city's urban food system. Food system planning is driven by physical land use planning and is led through cooperation between public agencies and professional planners. In 1975, the City Planning Act ensured the conservation of peri-urban agriculture as a green belt and cultural heritage resource, meaning that, in contrast to many other urbanising regions, agriculture was not alienated from the city. The Land Development Act reinforced the protection of farmland and the development of irrigation infrastructure. It also adopted soil fertility as a parameter for land use planning and steering urban growth. The Comprehensive Plan from 2013 promotes small-scale farming in the inner city. The government also supports street food vendors and mobile markets and built a central fresh food market where food from peri-urban farms is distributed. These city-level policies and strategies are complemented by NGOs and community-based organisations that promote building practices on the neighbourhood level, including shared edible green spaces, collective gardens and rooftop gardens (Boossabong, 2018).

Transnational conception of urban food systems

To end hunger, achieve food security, improve nutrition and promote sustainable agriculture is the second of the 17 UN SDGs to achieve a better and more sustainable future (United Nations, 2015). The UN has also acknowledged that cities play a major role in achieving this goal. The UN-Habitat 2009 report 'Planning Sustainable Cities' anticipated increased demand for urban agriculture spaces in cities due to rising transport caused by depleted energy resources. The report therefore postulates that 'Urban environments need to be planned so that they allow for urban agriculture to become an accepted element of the urban open space system and local fresh food markets a standard part of urban infrastructure' (UN-Habitat, 2009, p. 202). Ensuring food security and nutrition became a central principle in the UN New Urban Agenda 2017. Commitment No. 51 explicitly includes strengthening food system planning in the context of promoting the development of urban spatial frameworks and enhancing resource efficiency, urban resilience and environmental sustainability (United Nations, 2017). Additionally, the 2016 UN-Habitat World Cities report endorsed the integration of 'eco-friendly agriculture and provision of common land' in the planning of urban and peri-urban areas (UN-Habitat, 2016, p. 96). However, experts criticise a lack of strategies in the New Urban Agenda, addressing the shrinking of arable land and decrease of urban farmers (Cabannes and Marocchino, 2018)

A milestone for the legislation is the Milan Urban Food Policy Pact, launched in October 2015 with 45 original signatories. A total of 209 cities from all continents endorsed the latest declaration in 2019. Cities acknowledged that they have a strategic role in developing sustainable food systems and promoting healthy diets, noting that current food systems are challenged by environmental degradation, resource scarcity and unsustainable production and consumption patterns. Urban and peri-urban agriculture is encouraged to protect and integrate biodiversity and contribute to ecosystem services and human well-being (Milan Urban Food Policy Pact, 2015).

The current European Farm-To-Fork strategy as part of the European Green Deal emphasises that urban food systems are one of the key research areas to transition to sustainable food systems, recognising the 'inextricable links between healthy people, healthy societies and a healthy planet' (European Commission, 2020b, pp. 2, 15).

3.3 Urban agriculture as part of the urban food system

Of all process components of the urban food system, production in the form of urban agriculture is the most influential in physically shaping the urban environment and is the most important field of action in terms of spatial urban planning. Urban agriculture is the main infrastructure of urban food systems. Due to its spatial presence as a tangible and green infrastructure and interactive public space, it offers various forms for engaging civil society in placemaking.[4] In many cities, a vast share of urban agriculture only came into existence because of civil stakeholders. Urban agriculture has been deemed essential to rendering cities more sustainable. In addition to food production, it contributes to urban residents' livelihood in numerous ways and captures nutrients from the urban metabolism that otherwise are likely to pollute rivers and coastal waters (Girardet, 2005; Skar et al., 2020; Zeunert, 2018). The following definition describes the systemic and spatial dimension of urban agriculture in relation to urban systems and society:

> Urban agriculture spans all actors, communities, activities, places and economies that focus on biological production in a spatial context, which-according to local standards – is categorized as 'urban'. Urban agriculture takes place in intra- and periurban areas [. . .] urban agriculture is structurally embedded in the urban fabric; it is integrated into the social and cultural life, the economics, and the metabolism of the city. (Lohrberg et al., 2015, p. 21)

Current discourse includes the terms urban and peri-urban agriculture (UPA; (for example Cabannes and Marocchino, 2018) and urban and peri-urban agriculture and forestry (UPAF; (for example Russo et al., 2017). This dissertation uses the term urban agriculture to refer to intra- and peri-urban agricultural practices within an urban-rural gradient.

3.3.1 Conception of urban agriculture

Research on urban agriculture dates back to the 1960s, when French geographers started assessments in Central Africa, which were dominated by agricultural circles and neglected in urban planning for a long time (Mougeot, 2000). Urban agriculture discourse has intensified over the past two decades (Zeunert, 2018), along with the rediscovery of urban food system planning (Pothukuchi and Kaufman, 2000). Contemporary and new forms of urban agriculture in the Global North originated in North America and spread to Europe in the early 2000s, with Jac Smit, founder of the 'Urban Agriculture network', being a major disseminator (Bohn and Viljoen, 2014a, 2014b; Smit et al., 2001d). Urban agriculture is now widely understood as a valid type of urban space in scientific discourse. Its integration into cities' open space systems is a central aspect of urban food system planning. Urban agriculture is officially endorsed by international organisations such as UN-Habitat, but it has not yet caught on in the urban planning of most cities (see Box 4).

Related terms are 'urban farming', which emphasises yield over territorial consideration; 'urban gardening', particularly used among German activists; and 'urban horticulture', which is actually more precise than urban agriculture as it refers to crop cultivation but which is most used in the science of horticultural practice (Bohn and Viljoen, 2014a).

3.3.2 Prevalence of urban agriculture

Agriculture and the city have always been two poles that attract and repel each other simultaneously (see 4.6). Especially in Western culture, there is a historical dichotomy between the city and countryside, where agriculture is often perceived to belong (Giseke et al., 2015a). However, while the growth of cities consumes former agricultural land (see 2.3.2), securing food availability has been a reoccurring motivation for practicing urban agriculture in many cities through various development stages. Research has shown that urban agriculture was integral to ancient Mayan and Incan cities, to European and North American cities throughout urban growth in the 19th and 20th centuries, as well as to currently urbanising cities in the Global South (Smit et al., 2001c).

The regional and global extent of urban agriculture is far from coherently documented and up to date. Spatial analysis based on a dataset from 2000 determined that 11% of total irrigated cropland area is located within urban areas and 60% within a 20-km buffer zone of urban areas. In Southeast Asia, of the

[4] Referring to the collaborative process by which the public realm is shaped in order to maximise shared value, *'strengthening the connection between people and the places they share'* (Project for Public Spaces (PPS) (NGO), 2018).

total irrigated agriculture, about 10% is located in urban areas and about 55% within a buffer zone of 20 km, whereas of total rainfed agriculture less than 5% is located in urban areas, and about 30% is within a buffer zone of 20 km. In arid regions such as Oceania, of the total irrigated agriculture, about 40% is within a buffer zone of 20 km, compared to less than 10% of total rainfed agriculture (Thebo et al., 2014). The study of Thebo et al. reveals that a) global agriculture is significantly practiced in the vicinity of urban areas, b) the majority of urban agriculture is located in the peri-urban region and c) agricultural production in the vicinity of urban areas tends to more often be irrigated. In 2010, another global-scale study by Zezza et al. assessed survey-based data of urban agriculture from 15 developing countries. The single-country datasets were collected in different years, with the oldest coming from 1998 and the most recent from 2004. Zezza et al. found large variation in the share of households engaged in urban crop production, with levels such as 4% in Pakistan, 10% in Indonesia, and 18% in Bulgaria up to 65% in Nicaragua and Vietnam. Mean participation was 33% (Zezza and Tasciotti, 2010).

Urban agriculture is a potentially flexible land use that has been observed to dynamically increase and decrease in cities depending on a wide variety of socio-economic and cultural drivers. For example, surveys in Moscow demonstrated a stark increase from 20% to 65% of families engaged in urban agriculture between 1970 and 1991 due to economic struggles, the need for self-reliance and governmental incentives (Smit et al., 2001c). After the collapse of the Soviet Union and a slowly improving economic situation, the number of vegetable gardens decreased again from seven million in 1998 to 2.8 million in 2012, while in the same period the number of multi-purpose recreational gardens and dachas[5] decreased only slightly from 15.1 million to 14.2. Urban agriculture remains popular, involving an estimated 50% of Moscow's population in 2013 (Boukharaeva and Marloie, 2015). Another example is the city of Dar es Salaam, which had a similar sharp increase from 18% to 67% of families engaged in agriculture between 1967 and 1991. This trend is associated with rapid urban growth and migration of a former rural population familiar with agricultural practices. Observations have indicated that practicing farmers often had to be living in the city for some years before they were embedded in the social system well enough to obtain the resources necessary for urban agriculture (Schmidt, 2012). A study from 1998 estimated that 90% of the vegetables consumed in the city stem from urban agriculture (Orsini et al., 2013). In Tanzania, urban agriculture is widely practiced to counteract the food insecurity that affects 20% of Tanzania's population (Schmidt, 2012).

An increase in urban agriculture during the 1970s also took place in progressively post-industrialising cities of the US such as New York and Detroit (Neu and Nikolic, 2014). In fact, the largest community garden program in the US supports over 550 community gardens in New York City (New York City Department of Parks & Recreation, 2020). In Europe, allotment gardens have been a characteristic asset of many cities since they were found to improve living and nutrition conditions for workers during urban growth in the 19th century, and these activities increased during times of crisis in the 20th century. During the World Wars, half of the nutrition sources in terms of perishables was produced via urban and peri-urban agriculture (Smit et al., 2001c). Allotment gardens were intensified and expanded, and public and vacant land was also utilised (Demailly and Darly, 2017). Urban agriculture declined in the second half of the 20th century, but the established structure of allotment gardens has mostly remained, even if only part of them now serves for food production. Today, at least 3% of Berlin's total area is dedicated to allotment gardens (Senatsverwaltung für Umwelt, Verkehr und Klimaschutz, 2018).

A remarkable example of highly productive as well as resource-efficient, market-oriented urban agriculture is in Paris. Around 1900, a sixth of the total area of Paris was used to produce 100,000 tonnes of vegetables, or 50 kg per capita, thus exceeding local consumption levels. The incorporation of stable manure from horses and urban wastewater as fertiliser as well as heat and carbon dioxide from fermenting manure through greenhouses led to a nutrient cycle that was not only self-sufficient but even generated surplus growing media (Smit et al., 2001c). Due to the increasing scarcity of open land, this type of urban agriculture vanished, but it was replaced by temporary initiatives inspired by the community garden model that emerged in the early 2000s. At least 150 shared gardens on vacant lands in the city region have been formalised, alongside more informal projects (Demailly and Darly, 2017).

These examples illustrate how urban agriculture occurs worldwide in the Global South as well as in the Global North, though with divergent motivations and contributions to cities' food supplies. In the Global South, urban agriculture is mostly practiced and endorsed by UN bodies to combat food insecurity (Orsini et al., 2013). Historically, this has also been the case in the Global North. Nowadays, urban agriculture is

[5] 'An area of land with a home outside the city, purchased or received as a gift, used as a second home. The dacha is the basis for broad cultural creation.' (Boukharaeva and Marloie, 2015, p. 202) Originated in Russia, but the term is familiar in many languages by now.

often driven by growing environmental awareness and can be considered an expression of criticising consumer society (Barthel et al., 2016b). Socio-educational and cultural aspects connected to gardening as well as the greening of the city are in the foreground (Neu and Nikolic, 2014). The current contribution of urban agriculture projects to meet demand is estimated to be rather low but is potentially expandable within city regions (Wascher and Jeurissen, 2017). There are also regional differences within the Global North. Emerging urban agriculture projects in the US such as in hurricane-hit New Orleans, for example, are a reaction to low levels of social support services from the government. In the US, sharp urban segregation, neglect of public space, high levels of poverty and hunger led to a strong tradition of active self-help and community engagement (Neu and Nikolic, 2014).

These examples showcase how the prevalence of urban agriculture fluctuates and can be considered a flexible land use. However, land remains the essential resource, and areas that are built up are difficult to re-occupy with soil-bound urban agriculture. Soil is regularly displaced and lost due to urbanisation. Nonetheless, practitioners find new forms of urban agriculture by entering vacant land or rooftops or adding to existing green spaces such as private gardens or public parks (Zeunert, 2018).

3.3.3 Forms of urban agriculture

Urban agriculture is a complex, multifunctional and multidimensional phenomenon that evades clear-cut categorisation. It can be conceptualised through its spatial, technical and socio-economic dimensions.

3.3.3.1 Spatial dimensions

Elements of urban agriculture vary highly in size, location and scale. The physical manifestation of urban agriculture is the greatest determining factor for its technical, socio-economic and ecosystemic functioning and is a result of socio-economic and geographical conditions. Urban agriculture occurs in peri-urban as well as intra-urban areas and includes any form of formal or informal activities in the city *region* (Giseke et al., 2015b). Approaches to the differentiation between peri- and intra-urban vary depending on the context-specific demarcation of the city region and assessment approaches (Mougeot, 2000). For instance, according to the factual geospatial assessment of Thebo et al., a surrounding buffer zone of 20 km is considered peri-urban agriculture (Thebo et al., 2014). Technically, urban agriculture can be considered a continuum within the city region. The closer the elements are to dense polycentric urban structures and the more they interact in terms of supplying the local community, the more they can be considered *urban* agriculture.

The size of urban agriculture elements ranges from peri-urban large-scale open fields of several hectares to comparably smaller units that are more integrated into the urban fabric such as allotments or community gardens, which are typically 0.01–3 hectares (Zeunert, 2018) and micro units making use of small spaces on balconies, yards or within public spaces (Lovell, 2010; Orsini et al., 2013).

3.3.3.2 Technical dimensions

The spatial dimension is related to the technical setup and cultivation method of agricultural production sites. Agriculture is classified as animal keeping and crop production, with this dissertation focussing on the latter. Crop cultivation varies in terms of crop type, methods of irrigation, use of fertiliser, type of growing media (e.g., soil, hydroponics), location (e.g., soil-bound, raised bed) and level of mechanisation (e.g., use of tractors). Large-scale peri-urban agriculture tends to be mechanically operated, while smaller intra-urban units are more labour-intensive. Compared to rural agriculture, urban agriculture is more often irrigated, and cropping intensity for both irrigated and rainfed urban croplands has been found to be higher in urban areas and their buffer zones (Thebo et al., 2014). Main irrigation methods are surface irrigation with channels, flooding the whole field (basin irrigation), or sprinklers and drip irrigation. Drip irrigation is an advanced system with small diameter pipes and emitter outlets that only release a small amount of water close to the plants (FAO, 2016a).

The pressure of land scarcity in urban areas has sparked the development of technical systems that make efficient use of small spaces and are detached from the ground, making them suitable for building integrated production. A simple approach to making use of small spaces independent of local soil quality is raised beds. Technically more advanced systems are hydroponics, aeroponics or aquaponics. In hydroponic systems, plants sit in containers with mineral substrates such as clay aggregates or perlite and are provided with a nutrient solution via water. The major advantage with such a system is the absence of weeds and other soil-borne pests, no toxic pesticide residue, increased water and fertiliser efficiency, and better control over nutrients and oxygen. Aeroponics is another soilless cultivation method in which plants are exposed to nutrient-enriched mist (FAO, 2016b). Aquaponics is a combination of hydroponic and aquaculture in a closed circle. Nutrient-enriched water from aquaculture/fish tanks is utilised by plants and recirculated as purified water back to the aquaculture unit (Somerville et al., 2015).

Perishables such as vegetables and fruit are more common in urban agriculture, with annuals other than staple crops accounting for more than 70% (Thebo et al., 2014), which is logical given that grains and cereals are most commonly grown in large-scale fields. Moreover, cereals can be stored easily, while many types of vegetables and fruits perish quickly; thus, their production close to market infrastructure and consumers is beneficial (see 3.2.2.3). Indigenous leafy vegetables such as Amaranthus, cabbage, lettuce, coriander, and chives have been observed to offer urban producers a market niche (Orsini et al., 2013).

3.3.3.3 Socio-economic dimensions of urban agriculture

Urban agriculture is an expression of individual and societal values, aesthetics and socio-economic conditions. The following paragraphs give a brief overview of these topics.

Agriculture can be practiced for self-sufficiency as well as for selling to potential consumers close by. As illustrated, societies in regions with lower income or less governmental social support tend to practice urban agriculture to combat food insecurity, while socio-educational and cultural aspects are more important drivers in affluent societies (Neu and Nikolic, 2014; Orsini et al., 2013). Overall, those involved benefit from the freshness of produce and simple processes for food traceability (van Leeuwen et al., 2010). From the economic perspective, subsidies and land prices have a major influence on urban agriculture. Subsidies are prevalent in almost every country and have the main goal of ensuring plentiful food production and benefitting farmers' income by raising food prices above the free-market level and direct payments to farmers. Worldwide, subsidies are generally directed at starch-based production and animal feeds, with little attention given to fruits and vegetables, which is a disadvantage for small-scale urban farmers (Freund and Springmann, 2019). An example of alternative financial steering is Japan, where one third of all Japanese agricultural produce is generated through urban agriculture, partly due to targeted subsidies (Zeunert, 2018). Tokyo, one of the most populated and dense cities in the world, has preserved an urban agriculture space of 671 ha, or 2% of the city's territory (Niwa, 2012). Notably, the occurrence of urban agriculture strongly corresponds to the level of land prices, with an increase in prices generally leading to more construction and reduction of urban agriculture as seen for example in Casablanca, Morocco (Giseke, 2015). In Detroit, the sinking of prices and emergence of vacant lots has presented more opportunities for urban agriculture (Nicolin, 2019).

3.3.4 Clustered typologies

In scientific discourse, there are various approaches to identifying structural features and building typologies across these dimensions, which is helpful for a holistic assessment and operationalisation of urban planning (Smit et al., 2001a).

3.3.4.1 Review of selected urban agriculture typologies

The FAO's 2001 briefing guide for the implementation of urban and peri-urban agriculture distinguishes three major types (Drescher, 2001):

1) 'Urban micro-gardens and mushroom production as well as high value exotic ornamentals, condiments and aromatics' in densely populated areas with limited land access. This type can be building-integrated, such as backyards, balconies, or rooftops;
2) 'Highly intensive cultivation systems under localised irrigation methods and small-scale nurseries' operated by stakeholders that have access to small-size plots in mediocre populated urban areas;
3) 'Small-scale allotments' that are integrated into open urban spaces and peri-urban areas.

Smit et al. provides one of the more comprehensive assessments of potential spaces and scales of urban agriculture, mostly based on observations in developing countries (Smit et al., 2001a). They identified:

4) 'Around the House,' or the usage of yards or rooftops;
5) 'Community spaces', such as community or allotment gardens;
6) 'Surplus or Reserve Public and Private Spaces', such as parks as well as the open spaces of universities, schools, hospitals;
7) 'Industrial and Brownfield Areas', referring to urban agricultural production within industrial areas, such as sprout-growing in buildings as well as abandoned areas:
8) 'Roadsides and Other-Right-of-Way', or the use of long narrow plots along streets, railroad tracks, electric transmission lines, gas pipelines;
9) 'Streamsides and Floodplains', or fertile soils of areas that are regularly flooded and unsuitable for construction of buildings;
10) 'Water Bodies and Wetlands', meaning careful usage of selected water-related sites for fishing and aquaculture or aqua-terra farming;

11) ‘Steep Slopes’, which are unsuitable for buildings and useful for erosion-mitigating types of agriculture such as forestry or terraced horticulture.

Potential locations within the city regions where these types can occur are divided into city centres, high-density development corridors along highways and roads, wedges of lower density, and peri-urban transitional areas. Outer portions of a city have greater agricultural use.

Similarly, Lovell et al. classified five categories of potential application fields for urban agriculture through the dimension of scale and ownerships, mostly based on observations from North America (Lovell, 2010):

1) ’Built structures’, which emphasis how the built infrastructure is a potential site to incorporate production ranging from intense ‘vertical farms’ to containers on rooftops;
2) ‘Private parcels’, referring to entrepreneurial farms as well as residential backyard gardens;
3) ‘Public and institutional green spaces’, referring to possible integration strategies ranging from fruit trees to community gardens;
4) ‘Urban neighbourhoods’, which emphasis opportunities to integrate retrofitted urban agriculture;
5) ‘Entire cities’, referring to visionary urban design strategies such as that of ‘Continuous Productive Urban Landscapes’ (see 4.4) but also other efforts for implementation on the city level (e.g., Portland and Philadelphia).

Orsini at al. identified four types of ‘traditional’ cultivation systems and two types of ‘innovative systems’ of urban horticulture to understand crop-producing activities within urban agriculture (Orsini et al., 2013). Traditional systems comprise:

1) ‘Mixed farming systems on a limited acreage first target household’, including backyard or community gardens;
2) ‘Extensive monocropping for both home consumption and market’, or small farms at the periphery of the city without irrigation, such as production of starchy roots like cassava and sweet potatoes at the slopes of peri-urban settlements in sub-Saharan Africa;
3) ‘Shifting cultivation systems’, a regionally specific type referring to cropping systems in tropical regions where the forest is cut down, the vegetation burned and successive crops grown;
4) ‘Intensive horticultural cropping system and on medium- or large-scale farms’, meaning market-oriented, ‘real’ agricultural farms. In this final type, as opposed to type 2, irrigation and fertilising is applied.

Innovative cropping systems address low soil fertility or water availability, minimise environmental impact and make use of limited space, making these systems applicable to dense urban areas. Two types are distinguished here:

1) ’organoponics’, which is production based on an organic substrate typically through containers, which makes production independent from local soil quality;
2) ‘simplified hydroponic systems’.

Nasr et al. proposed typologies that have become common practice using examples from the US and Canada (Nasr et al., 2014). 1). These include

1) the ‘Multipurpose rooftop’, including restaurants that grow ingredients on their own roof or housing projects incorporating rooftop mini-allotments;
2) ‘Urban greenhouse’, or greenhouses that extend seasons and enable the growing of specialised crops, seeds and seedlings;
3) ‘Productive housing’, referring to any type of residential food production in dense areas, including utilising balconies or backyards;
4) ‘Fertile Neighbourhood’, which expands the aforementioned potential initiatives to the neighbourhood level.

A different perspective is gained from the transdisciplinary research project ‘Urban Agriculture as an Integrative Factor of Climate-Optimised Urban Development, Casablanca / Morocco’ (2008–2013; (Giseke et al., 2015c). Based on analyses of existing conditions that are suitable for integration into upcoming urbanisation processes, the research team envisioned nine novel morphological categories of urban agriculture (Giseke, 2015). The generation process stressed urban agriculture as a hybrid between urban and rural subsystems that builds on polycentric modelling of the city in urban core areas, fringes, corridors, urban-rural affected and rural core areas. The typologies were systemically composed based on the parameters of their vision, ‘talent’ and transition drift as well as their inherent urban, agriculture and landscape components. The categories include the following (Giseke et al., 2015d).:

1) ‘Precise urban agriculture’ refers to small-scale productive green spaces in densely built-up areas including open spaces, private gardens, roofs and facades;

2) ‘Beautiful Productive Greenbelt’ is thought of as a mosaic of different open spaces with integrated productive units that form a greenbelt close to city neighbourhoods with high and medium density;
3) ‘Parasitic Backpack Agriculture’ envisions building-integrated food production, processing and distribution within industrial corridors.

This is followed by a set of peri-urban typologies which differ primarily in terms of their spatial configuration:

4) ‘Rural Stripes’ – urban and agricultural ‘ribbons’ forming alternating axes;
5) ‘Rurban Microfabrics’ – small clusters;
6) ‘Country Town’ – small suburban towns that are anticipated to become urban centres in the polycentric structure;
7) ‘Agroforopolis’ – combining agricultural areas with agroforestry and rural settlements;
8) ‘Beautiful Productive Landscapes’ – small-scale parcels in river valleys and hilled topography;
9) ‘Hyper-productive Rural Landscapes’ – large-scale parcels on fertile land with flat topography.

3.3.4.2 Conclusion

The reviewed typologies are built across spatial, technical, socio-economic and geographical dimensions. They have divergent underlying logics and are difficult to compare. Some describe current practices (e.g., Nasr et al.), while others are typologies designed for urban planning and urban growth (e.g., Giseke et al.). However, they share structural similarities, as illustrated in Figure 7. The typologies can be placed along an urban-rural gradient, ranging from small-scale or micro units in dense urban cores to peri-urban, large-scale productive areas, with numerous types in between.

A recurrent feature is the integration of productive units into building structures and classification according to specific cultivation technologies that are also indicators for scale and size, such as small-scale hydroponic systems. The urban-rural gradient runs parallel to own-supply versus market-oriented production, which overlap and are not always distinct. Studies have determined that any household involved in urban agriculture is always a producer and consumer (Ruel et al., 1998). However, some smaller entities might not always generate enough surplus for selling, and some larger, industrially organised farms exceed the definition of family-based/private production and hence consumption.

Another motif is distinction according to ownership, such as private land, community spaces including allotment types, public spaces, and industrially used spaces such as right-of-way spaces of other infrastructures (e.g., gas pipes).

Giseke et al.’s classification of morphologies considers context-specific geographical conditions because their classification was tailored for the region of Gran Casablanca and designed from the perspective of landscape architects. Moreover, the generalised classification of Smit et al., which was based on observations of urban agriculture, considers typical geographic conditions that characterise production such as water-related geographies and strong topographies with steep slopes.

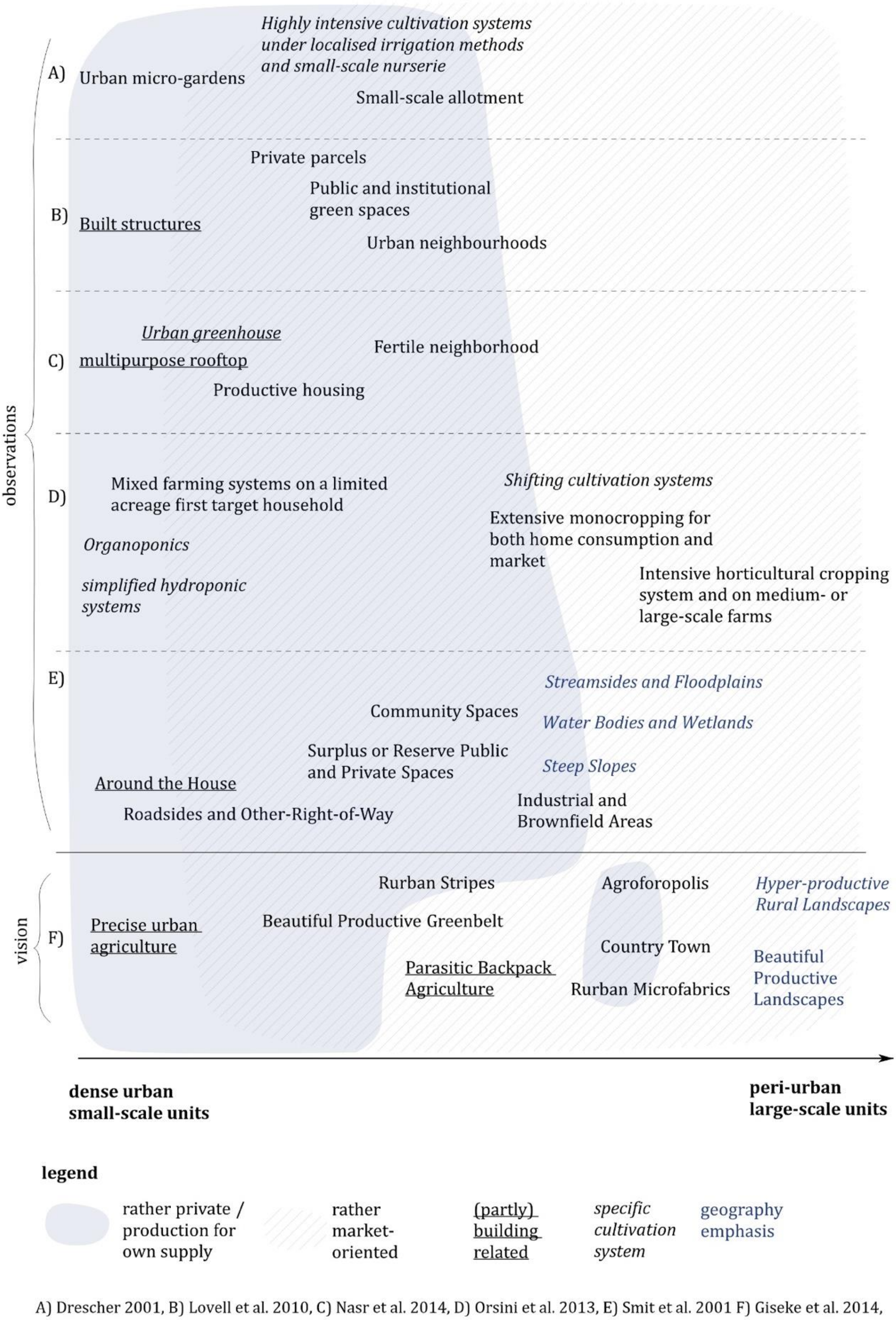

Figure 7 Review of urban agriculture typologies

3.4 Infrastructures facilitate resource flows and shape the urban metabolism

When examining and potentially optimising the urban metabolism against the changes of the Anthropocene, the importance of infrastructure systems cannot be overestimated. Historically, infrastructure was defined as the foundation of the economy as a prerequisite for the production, distribution and use of goods and services. Infrastructure comprises the entirety of physical, institutional and human facilities the economy relies on (Jochimsen, 1966). Infrastructure is a medium of geography that prepares the ground for future building and events by dividing, allocating, constructing surfaces and providing services through establishing networks of movements, communications and exchange (Allen, 1999, p. 54). As the basic structures of our societies, infrastructures are the spatial entities that facilitate resource flows and ecologically relevant everyday practices (Kropp, 2018; Prytula, 2019). Infrastructures form the interface of the provision of resources and disposal of waste from the urban metabolism. They determine the effectiveness of resource use (Oswald et al., 2003). In this sense, infrastructures are 'a series of interconnecting life support systems' (Gandy, 2005, p. 28) and the 'nerve networks of the superorganism humanity' (Radermacher, 2005, p. 104).

Due to their seemingly 'banality' in terms of their pragmatic function, infrastructures were long overlooked by designers and architects, but they are increasingly being recognised as a 'great enabler, the glue of urbanisation' (Bélanger, 2017, p. 437) and as the 'actual frontier' of reformation (Joachim and Fessel, 2013, p. 270).

> Designers' responsibility is to re-tool the middle ground, the in-between, and the nexus points. In this case, infrastructure with applied innovative ecological directives becomes the penultimate goal, before completely reforming the world. (Joachim and Fessel, 2013, p. 270)

3.4.1 Current state of infrastructure development

3.4.1.1 The paradigm of the 'hygienist city' has decoupled processes

Along with divergent urbanisation processes, infrastructure development is at different stages in the Global North and the Global South. Generally, the major phases of urban growth and infrastructure development in most industrialised countries took place in the 19th and 20th centuries, and current population growth and urbanisation processes are now mainly happening in developing and newly industrialising countries in the Global South. In 'old' industrialised countries, major decisions regarding infrastructure setups were made under different conditions in the 19th century, when the chaos of the industrial cities or 'bacteriological cities' was tackled by the agenda of the 'hygienist city' (Gandy, 2004). In this period, infrastructure projects contributed to public health, expanded participation opportunities, and resolved distribution conflicts with promises of growth (Kropp, 2018). Bodily functions and adherent metabolic exchange processes with the city were concealed in the ground in the form of sewage systems and left to engineers (Gandy, 2004; Giseke, 2018).

> ... the gloss of contemporary urban life – safe, stable, accessible – is maintained by the illusion of permanence that infrastructure outwardly projects. Beyond the seamless buff of technological and mechanical systems, very rarely do we see the physical extents of this vast, often underground infrastructural territory, let alone understand the longevity of this large, technological apparatus. (Bélanger, 2017, p. 58)

Wastewater and urban rainwater are made to disappear as quickly as possible through sewage systems. Different urban flows that used to be interdependent have become disconnected (Wiskerke, 2015). Today, these invisible and large-scale systems hinder adjustment and transformation to the new sustainability agenda.

3.4.1.2 Path dependency in infrastructure development

The design of infrastructure represents the most important component of rendering the urban metabolism more sustainable. However, one reason previous global efforts for sustainable change have been so slow is tat infrastructures are complex and of somewhat '*resistant'* character (Binz and Truffer, 2009; Kropp, 2018); this holds true particularly for large-scale and centrally managed systems. As a hybrid structure of social and technical components that facilitate resource flows between urban and natural systems, infrastructure's immanent feature is an expansive need for 'environmental control' (Kropp, 2018). Their extended network systems and high initial investment costs make them natural monopolies. In this way, infrastructure systems develop their own dynamics or 'momentum', which contributes to their resistance against reconfiguration. Large parts of crucial infrastructure systems, such as pipes for water and sewage as well as cables, are physically hidden in the ground (Gandy, 2004). Their functioning is often discreet and invisible. Only their dysfunction, such as a power cut, makes them abruptly come to mind (Bélanger, 2017). Responsibilities for developing and managing infrastructures are increasingly fragmented and multiplied since large-scale infrastructure systems have shifted from regional to state monopolies to trans-national, liberalised organisations. The spatial and temporal expansion of infrastructures reinforces these dynamics and creates powerful complexes of mutually stabilised properties. To change infrastructure systems requires reconfiguring various components in different subsystems, which further increases complexity. The characteristics of large-scale infrastructure systems entail path dependencies and hinder innovation (Kropp, 2018).

3.4.1.3 Potentials in regions of urban growth

Major infrastructure development is currently happening in developing and newly industrialised countries. Infrastructure investments are a pressing issue as urbanisation in many regions has preceded infrastructure development (Pellegrino et al., 2015). The concept of 'leapfrogging' has been discussed at length in sustainable transition theory and maintains that developing countries learn from the mistakes of more developed countries. These mistakes include investment in so-called ''dinosaur' infrastructures that in the end will make it more difficult to reach inherent sustainability' (Tukker, 2005, p. 79).

Continuing globalisation and rapid overall development, especially in Southeast Asian infrastructure sectors, provide 'unique windows of opportunity for implementing eco-innovations and thus lead to sustainability transitions in different sectors' (Binz and Truffer, 2009, p. 2). A well-known example is mobile telephone development that has skipped the implementation of landlines in developing countries. Similar potentials are also being discussed regarding wastewater management and urban stormwater management through blue-green infrastructure (see 3.5.2).

In wastewater technologies, recent research on microbial structures in activated sludge plants has produced improved technology, though this technology is rarely applied because of high initial investment costs and additional energy use. In developing countries, sewage coverage and sewage treatment are overall still low and are either managed through centralised activated sludge systems or decentralised technologies. The resulting sludge from centralised systems is often poorly managed and poses health and environmental risks. In this context, the construction of smaller, decentralised and community-managed systems and enhancement of resource recovery is recommended (van Loosdrecht and Brdjanovic, 2014). More specifically, decentralised systems based on membrane bioreactor technology have been identified as a leapfrogging option that reduces freshwater use and costs for the construction and maintenance of large sewer networks (Binz and Truffer, 2009). Successful implementation of decentralized wastewater systems in newly industrialised regions and re-importation to 'locked-in' industrialised countries can contribute to the global sustainability transition (Binz and Truffer, 2009).

Regarding stormwater management and dealing with the effects of climate change, infrastructure investment in developing countries is often focused on 'engineered risk reduction' and 'grey' infrastructure. In contrast, increasing resilience through 'nature-based solutions'[6] and more adaptive blue-green infrastructure does not receive enough attention in studies and policies (Di Leo et al., 2016), which has been identified a potentially missed opportunity:

> The world's emerging and developing cities therefore have the unique opportunity to 'get it right the first time' and 'leapfrog' the modernist/industrial phase of monofunctional, low-performance, unsustainable industrial infrastructure – and start de novo with a multifunctional ecosystem services–oriented green infrastructure (Pellegrino et al., 2015, p. 387)

3.4.2 Alternative approaches to infrastructure development

In light of human-induced planetary alterations, comprehension of infrastructures has broadened in contemporary research. Since the character of large-scale infrastructure systems appears to exceed manageability and is obstructing needed renewal processes, striving for more decentralised and flexible structures might open new opportunities and courses of action.

[6]'…actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits' (Cohen-Shacham et al., 2016)

3.4.2.1 Decentralisation

The discourse regarding improved resource management through decentralised systems is growing across all sectors. In 1995, the UN Capital Development Fund (UNCDF) noted that decentralisation, as in delegating responsibilities for the provision of basic infrastructure to the local level, better ensures efficiency and sustainability: '(i) what is provided is really what is needed and (ii) that it is managed and maintained in the long run' (UNCDF, 1995 cited in UNDP, 1999, p. 14). This discourse is connected to the political principle of subsidiarity (Cabannes and Marocchino 2018), which refers to central authorities only performing those tasks which cannot be performed at a more local level.

Besides governance, there are potential technical benefits to more decentralised systems. For example, decentralised wastewater systems are considered to provide more opportunities to recycle and reuse resources due to increased accessibility in smaller units. Depending on the infrastructural configuration and the local geographical and climatic context, the use and waste of resources can be decreased, which benefits the goals of a circular economy and sustainability (Capodaglio, 2017) (see 3.1.4).

The decentralisation debate is also strong regarding energy systems. The dominant centralised energy systems were developed on the basis of industrial utilisation of fossil energy carriers (Prytula, 2011). While the global energy market still largely relies on oil and gas, the political agenda to reduce greenhouse gas emissions promotes a paradigm shift towards renewable energy sources that are facilitated through decentralised systems. Flare-ups of geopolitical conflicts and problematisation of trans-national dependencies, transportation-related hazards and high volatility of price regimes for primary energy carriers like oil are heating the debate. Increasing small-scale microgrids would allow consumers to control their energy use and allow them to become 'prosumers' (consumer and producer at once; (Leal-Arcas et al., 2019).

Regarding food systems, relevant movements examine the potential of regional production and are characterised by the diversification of actors (see 3.2.2.1 and 4.4.2). Assessing and enhancing the potential of intra- and peri-urban agriculture is increasingly part of municipal planning (Wiskerke, 2015), and various citizen-based projects have emerged (Barthel et al., 2016b) (see also 2.3.3, 3.2 and Box 4).

3.4.2.2 Participatory design and management

Drawing from the concept of infrastructural urbanism, infrastructures should be flexible, anticipatory, and open to change through management and cultivation that recognise the collective nature of the city (Allen, 1999, p. 55). Decentralising infrastructure systems naturally decentralises responsibilities and requires adapted modalities for collaboration and participation. If the design of infrastructure systems is 're-appropriated' by larger fractions of civil society, the conditions that determine the channelling of resources and hence ecological footprint can be progressively transformed to be more reflective and experimental (Kropp, 2018). For instance, decentralised wastewater treatment decisions are generally made and discussed at the local level (Capodaglio, 2017). The role of potential 'prosumers' illustrates the relevance of civil society (Leal-Arcas et al., 2019). As stated in Section 0, of all infrastructure systems, urban agriculture is the most characterised by the participatory processes of a broad range of civil actors as it represents a tangible green infrastructure and interactive public space. In many cities, urban agriculture is a dispersed structure, and the individual units are initiated and maintained by individual actors (see 3.3.2).

Thus, envisioning infrastructure setups aimed at an optimised urban metabolism relies on understanding potential stakeholder roles and networks. Any transition of the infrastructure setup and reconfiguration of resource flows is bound to social practices. It is citizens who potentially install solar panels, use greywater, cultivate rooftop gardens or dispose of and separate organic wastes.

Against this background, different transdisciplinary research formats have gained momentum as a move towards social change and greater sustainability (Grunwald et al., 2020). Transformative design procedures that take civic potential into account connect theoretical, empirical and design knowledge and create solutions for complex urban environments (Wieck, 2018). Civil society's involvement in design and management processes requires broad formats of participation as well as certain levels of perceptibility and accessibility for infrastructure elements that deviate from the previous invisibility principle of the 'hygienic city'.

Formats range from real-world labs with transdisciplinary pilot projects to innovation groups consisting of scientists and practitioners working together on topics such as land management or energy supply and projects based on citizen science, in which volunteers contribute to data collection. Real-world labs are especially suitable formats for exploring innovative infrastructure setups on smaller scales and can be used to launch and observe transformative processes and learn more about causes, effects, and interactions (Grunwald et al., 2020, p. 108).

3.4.2.3 Active involvement of natural systems in infrastructure systems

Acknowledgment of urban-natural interdependency anticipates a more pro-active involvement of natural systems in the process of resource exchanges and urban development.

> Extending the view of interaction and exchange processes as cooperation with the natural sphere means assigning agency to nature as well as accepting its hybridization through technical infrastructure and social entities. (Giseke et al., 2015e, p. 308)

Infrastructural urbanism metaphorically describes regular 'hard' infrastructures (roads, sewage, telecommunication) as 'artificial ecologies' due to their ability to manage flows of energy and resources (Allen, 1999, p. 57). Discourse has now moved beyond the metaphorical level and endorses 'soft, leaner infrastructure' (Bélanger, 2017, p. 447) composed of 'living networks of the biosphere' (Perrotti, 2015, p. 72). Basic urban services have to be rebundled and redesigned as 'living landscapes' (Perrotti, 2015, p. 72) to generate synergies between green, grey and blue infrastructure systems and to respond better to dynamic urbanisation processes and the agenda of sustainable urban development.

> These synergies seem to better support fluid, dynamic patterns of urban growth (i.e., the flow of waters, waste, energy, and food, which mostly transcend geopolitical borders) instead of reproducing or consolidating the vertical, centralised, and inflexible structure of modern 'industrial' cities. (Perrotti, 2015, p. 72)

3.5 Green infrastructure

Green infrastructure is an emerging concept and strategic planning approach that has the potential to mitigate a multitude of pressing Anthropocene challenges (Andersson et al., 2014; Norman and Alexandra, 2019). Green infrastructure has the potential to meet the principles mentioned in Section 3.4.2. It consists of a network of functionally or spatially connected entities that can contribute to decentralised, tightened resource loops. The adherent land use practices depend on a large network of collaborating stakeholders. Green infrastructure's most relevant trait lies in its approach to engaging with natural systems in a mutually beneficial way. Visible and tangible infrastructure greatly determines the atmosphere and quality of life in cities.

Green infrastructure is more than the sum of commonly understood green spaces. It refers to both a) a strategic planning concept to qualify and interconnect various types of green spaces that render them a part of green infrastructure and b) the spatial structure of natural and semi-natural elements itself (Benedict and McMahon, 2006). Moreover, green spaces are often understood as public green areas used predominantly for recreation (WHO, 2016). Green infrastructure is based on a broader view of green spaces and also includes areas not designated explicitly for recreation, such as agricultural areas, forests or any type of water body.

3.5.1 Conception of green infrastructure

Since its introduction in 2000, the concept of green infrastructure has been mostly consolidated in the Anglosphere and Europe (Mell, 2017; Norman and Alexandra, 2019). However, researchers and planners from different geographical and disciplinary backgrounds have highlighted numerous foci of the concept (Lennon, 2014; Mell, 2017; Wright, 2011).

The European Commission promotes the following definition:

> Green infrastructure (GI) is 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. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings. (European Commission, 2019b)

Green infrastructure is located in urban as well as rural areas (European Commission, 2013b). The emphasis on 'natural' and 'semi-natural' areas and 'ecosystem services' reflects that the EU closely links the concept of green infrastructure with its Biodiversity Strategy. However, the declaration of green spaces as part of green infrastructure is not unconditional; the definition is scale-dependent and site-specific. For instance, on the local scale, it can include biodiversity-rich parks, gardens and green roofs as long as they deliver multiple ecosystem services (European Commission, 2013c).

The strategy for urban green infrastructure in Germany stresses that besides vegetation- and water-related areas, other surfaces of urban areas such as rooftops or facades can be or can become part of the green infrastructure. Sealed and built-up areas can be qualified as part of the green infrastructure by unsealing, greening and planting trees. Urban green infrastructure complements grey infrastructure and can partially replace it, but the concept also confirms that these spaces have to fulfil certain context-specific requirements to qualify as green infrastructure (Hansen et al., 2018).

The concept of green infrastructure is closely linked with 'ecosystem services' (Coutts and Hahn, 2015; Hansen, 2018), a concept that acknowledges direct and indirect contributions to human well-being in terms of economic, material, health or psychological benefits. Since the Millennium Ecosystem Assessment of the United Nations and subsequent studies of the global TEEB initiative (The Economics of Ecosystems and Biodiversity), ecosystem services are an internationally endorsed guiding concept (Kowarik and Bartz, 2016). Supporting services refer to essential ecosystem functions such as nutrient cycling or soil formation. On this basis, ecosystem services are classified as provisioning services (e.g., food, freshwater), regulating services (e.g., climate or flood regulation), and cultural services (e.g., aesthetic, spiritual, recreational; (Millennium Ecosystem Assessment (Program), 2005). The aim to functionally and spatially connect ecosystems through the concept of green infrastructure emphasises the importance of ecosystem goods and services for society (Karhu, 2010).

Green infrastructure operationalises the agenda of sustainable urban development by ensuring the physical implementation and maintenance of green spaces and their ecosystem functioning. The planning approach focusses on developing green infrastructure elements as a network with high quality elements in terms of usability, biodiversity and aesthetics. Regarding socially, economically and ecologically sustainable urban development, green infrastructure can contribute to a wide range of goals. These include promoting health and well-being physically and mentally, sustainable land use, adapting to climate change and enhancing biodiversity (Hansen, 2018; Hansen et al., 2018). According to the recent EU research project GREEN SURGE (2013-2017), the unifying key principles of green infrastructure are (Hansen et al., 2017b, p. iv):

- Green-grey integration – combining green and grey infrastructures
- Connectivity – creating green space networks
- Multifunctionality – delivering and enhancing multiple functions and services
- Social inclusion – collaborative and participatory planning

However, the perception of green infrastructure and food systems as essential urban infrastructure systems is a relatively new concept that needs further examination. Until recently, publications listed only energy; water; sewage and waste management; supply of goods and logistics; transport and traffic systems; modern communication technologies (Oswald et al., 2003); and aspects of social infrastructure such as facilities of education, culture, health and leisure (Libbe et al., 2010) as crucial infrastructures. Baccini's more recent framework *Metabolism of the Anthroposphere* does list food, along with energy, information, and water, as an input infrastructure (Baccini and Brunner, 2012). In addition, the more recent framework 'planning sustainable cities, an infrastructure-based approach' defines landscape and food as two major infrastructure systems beyond transportation, water, energy, solid waste and information (Pollalis, 2016).

3.5.2 Blue-green infrastructure as a related approach

Given climate change's pressing challenges, cities worldwide are increasingly aiming to harness the potential of blue-green infrastructure, which focusses on synergies between green spaces and water management. Blue-green cities aim to reintroduce the natural water cycle into urban environments and provide effective measures to manage fluvial (river), coastal and pluvial (urban runoff or surface water) flooding. This is a paradigm shift from building centralized sewage systems and managing storm water 'outside' the city as quickly as possible to capture stormwater locally and allowing it to evaporate and trickle into the ground which overall leads to slow down its flow rate (Fenner, 2020). Green infrastructure plays a key role as it enables soil filtration, groundwater recharge and evapotranspiration. Thus, the urban system is regaining some of the capabilities of natural ecosystems.

This paradigm shift emerged in different ways in different cities, ranging from the 'sustainable urban drainage systems' (SUDS) used in the United Kingdom to 'low-impact development' (LID) in the United States, 'Water Sensitive Urban Design' (WSUD) in Australia and the 'Sponge City' in China and Germany (German examples cf. Becker, 2016; Thorne et al., 2018). The LID and SUDS approaches focus on the specific problem of restricted natural water cycles in urban areas in terms of surface runoff and flooding. The goal of SUDS is to reproduce water infiltration capacity in urban areas and reduce surface runoff. Further implementing SUDS is supposed to improve surface runoff's quality and conserve the natural characteristics of water bodies. Within the LID movement, the overall goal is to preserve a site's pre-development hydrology (Dietz, 2007). The WSUD approach aims to see all streams of water being managed as a resource, as they have quantitative and qualitative impacts on land, water and biodiversity, and the community's aesthetic and recreational enjoyment of waterways (Joint Steering Committee for Water Sensitive Cities, 2009).

3.5.3 Strategic spatial planning of green infrastructure

Green infrastructure is part of the tradition of strategically planning networks of green spaces as a subject of urban, environmental and landscape planning in the course of urbanisation processes in the US and Europe in the late 19th century (see Box 5). The inherent principle of green infrastructure to create a network of structurally or functionally connected multifunctional green space elements requires strategic planning processes at larger scales that are conducted by interdisciplinary teams of landscape architects and professionals from the fields of environmental and urban planning.

City-wide formal urban and landscape plans, masterplans and informal green space planning guidelines and strategies are described as the major tools for implementing urban green infrastructure (Hansen et al., 2018, 2017a). Additionally, the German Federal Government's white paper 'Green Spaces' states that the creation, maintenance and preservation of urban green spaces as part of integrated sustainable urban development must be derived from 'overall urban strategies and concepts' (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) et al., 2018, pp. 7–9). In this case, green infrastructure is understood as a 'cross-sectional task which requires interdepartmental cooperation (p. 10).

3.5.3.1 City-wide green space strategies and distinct figures

The stage and intensity of urbanisation greatly influence the driving forces of developing strategic networks of urban green spaces. Olmsted's innovative multifunctional 'Emerald Necklace' park network established in Boston in 1870 is one of the first applications of green infrastructure planning and broke new ground in the history of green space planning in the US and Europe. It sparked an expansion in scope from single 'decorative' and 'sanitary' green spaces at the neighbourhood level to strategic planning on larger scales (Lemes de Oliveira, 2017, p. 21; Lohrberg, 2001, p. 9).

In the years of rapid industrial expansion and urbanisation in Europe and the US, the aim to create overarching green space systems resulted in the development of distinct figures. Concentric green space systems such as green belts were seen as a solution to ensuring access to green spaces in rapidly growing cities. At the time, it was suggested that residents should be able to reach these green belts within half an hour (in Schöbel, 2007, p. 32).[7] Along with restructuring urban areas to facilitate transportation, radial systems and green wedges were proposed that better link urban areas with their surroundings (Lemes de Oliveira, 2017). Agricultural areas, particularly those along riversides, were often integrated into these green systems and considered scenic elements. However, the recreation, sanitation and structuring of densely populated cities were the prime motivations, as opposed to provisioning (Lohrberg, 2001, pp. 11–15). In the 1920s, planning increasingly aimed at decentralising urban areas where green space systems served to structure whole city regions, which ultimately led to models in which agriculture and self-contained settlements were a central theme, such as Ebenezer Howard's Garden City (see also Box 5).

Overarching green space systems were successfully implemented in many cities at some stage of urbanisation. Radial green systems are still prominent in the urban structure of Copenhagen from the 1947 Finger Plan as well as in Hamburg due to the 1920 Feather Plan. Green belts still characterise the urban structure of, for example, London, Cologne and Vienna (Xie et al., 2020, pp. 2–3). Green belt planning is particularly common in the United Kingdom. Many regions are equipped with green belts, which have grown in popularity and hence resilience over time. The United Kingdom's government's attempt to deregulate green belt policies and allow land turnover for new buildings failed because residents mobilised and generated political pressure for increased protection of green belts (Thomas and Littlewood, 2010, p. 5).

[7] As demanded by Countess Adelheid Dohna-Poninski in 1874 under the pseudonym Arminius.

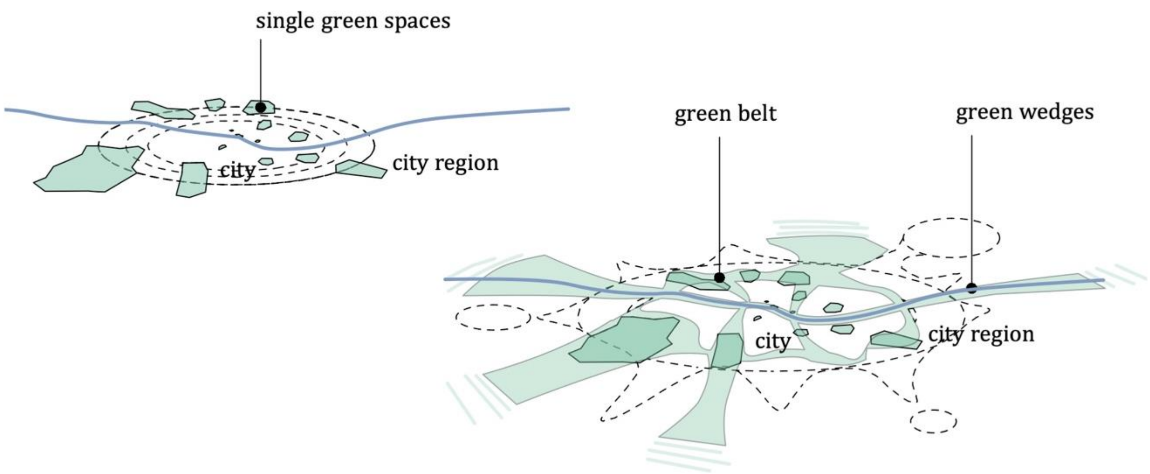

Figure 8 Stylised scheme of green space planning in growing cities

Gradually, explicit figures of self-founded and image-giving green spaces on large scales such as green belts and axes have been criticised for remaining stylistic graphics on paper that fail to be translated into built reality. At the same time, some scholars have criticised green belts for being too inflexible. Their rigidity inhibits adaptation to ongoing urbanisation processes and ultimately leads to new housing construction projects that are improperly misplaced in the periphery, as has occurred in planning practices in the United Kingdom (Schöbel, 2007, pp. 116–117).

Initially distinct green space figures often became progressively more complex. In the case of Hamburg, the planning answer to rapid urbanisation in the 1920s was the Feather Plan by Fritz Schumacher, which was supposed to guide the 'natural development of the organism of Hamburg' (title of Schumacher's plan in Machleidt + Partner et al., 2007, p. 30). The plan describes settlement axes that also define landscape axes, connecting the city's core with its surroundings. The concept has defined Hamburg's basic structure up to today and was refined and adjusted by several thematic planning frameworks. In 1989, an independent report consolidated the 'landscape axis program', with Fritz Schumacher's statement quoted in the opening of the report: 'Construction areas also arise if you do not take care of them. Open spaces disappear if you do not take care of them.' (Fritz Schumacher 1932 in EGL, Entwicklung und Gestaltung von Landschaft and PPL, Planungsgruppe Professor Laage, 1989, p. 2).

The axes are defined by the remaining natural structures, such as watercourses and their accompanying green systems; agricultural areas of arable and grasslands; and marshland with vegetable, fruit and flower crops. Wide at the periphery, the axes become narrower and more fragmented in densely built-up areas. The city intends to close these remaining gaps (BUE Hamburg, 2020a). In 2015, the city launched a project to strengthen one of its major landscape axes, the Horner Geest. Building on contemporary themes including mobility, experiencing urban nature and aspects of agriculture and resource flows, a range of measures were identified that increase green space quality and quantity (bgmr Landschaftsarchitekten and minigram, 2017). Today, the landscape axes and two green belts form the basic structure of Hamburg's green network. Hamburg recently adopted the green infrastructure strategy and developed a specialised plan called connecting green, which includes the existing and desired green network and contains central spatial objectives in terms of urban climate, habitat connectivity and recreation (BUE Hamburg, 2020b).

3.5.3.2 Landscape connectivity and green infrastructure

Since the discourse of green infrastructure is strongly influenced by efforts to preserve biodiversity (see Box 5), the principles of landscape and habitat connectivity were incorporated in the concept of green infrastructure early on.

The subject of landscape connectivity is a response to the increased fragmentation of habitats through the expansion of urban areas and infrastructures. Landscape connectivity is defined as 'an attribute of an entire landscape, where the scale of the landscape is determined by the movement scales of the species of interest' (Tischendorf and Fahrig, 2000, p. 16). Structural landscape connectivity is based on physical characteristics. Functional landscape connectivity considers the dimension of behavioural responses of organisms in relation to landscape elements. Even though habitats may not be physically connected, certain creatures may travel to reach other habitats (Tischendorf and Fahrig, 2000, p. 8). More recently, research has underlined temporal aspects of species behaviour and species' ability to survive in landscapes and recolonise, for example, due to habitat changes by global warming (Auffret et al., 2015, p. 57).

The legal protection of habitats that are particularly important for biological diversity is an established means of nature conservation that directly impacts spatial planning because urban development is restricted or entirely inhibited. For example, the EU Biodiversity Strategy's core intention is to improve and widen the network of protected areas. The current goal is to raise protected areas from 26% to 30% of land and from 11% to 30% of the sea (European Commission, 2020c, pp. 3–4). To maintain populations and their genetic diversity, developing corridors and stepping stones between isolated habitat patches are measures to conserve biodiversity. Studies have documented the use of corridors by different types of species, including insects, small mammals and bird-dispersed plants (Haddad et al., 2003). Corridors are particularly beneficial for animal species that are known to search for dispersal passages. The spatial arrangement in species that find new habitat patches by chance is less relevant. Overall, the main factor determining whether populations can spread is observed to be the distance between habitat patches (Fahrig and Paloheimo, 1988, pp. 195; 211). Studies have discovered that the composition of the habitat matrix surrounding stepping stones and corridors greatly determines interpatch dispersal (Baum et al., 2004).

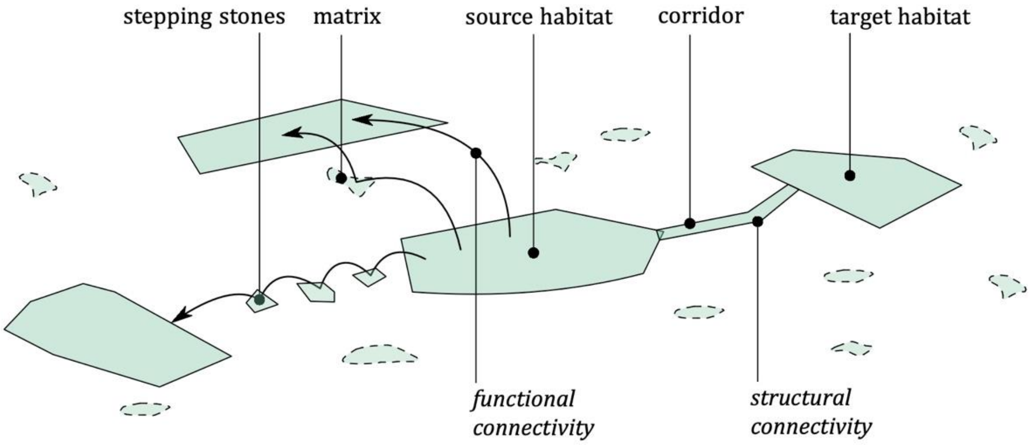

Figure 9 Stylised scheme of habitat connectivity, based on Baum et al. 2004 regarding the distinction between single small patches forming the general matrix and stepping stones coming close to forming a corridor

3.5.3.3 Green infrastructure as a spatial approach

The increasing complexity of spatial and social-ecological structures in growing urban regions has led to a multiplication of requirements for green space systems to address with green infrastructure. Green infrastructure's implementation touches on various and overlapping functions in terms of urban challenges such as climate change adaptation, biodiversity and social cohesion (Hansen et al., 2017b, pp. 7–20). Serving these functions requires distinct and context-specific spatial and functional configuration of green infrastructure networks on the relevant scale. For example, air ventilation corridors must be open, wind-permeable spaces, while other functions such as habitat connectivity or cooling may be targeted through forested elements.

Creating a green infrastructure network requires a spatial mapping and analysis of potentially suitable sites, including 'green baseline elements' and 'grey sites offering potential' (Hansen et al., 2017a, pp. 11–12).

Baseline elements consist of four major categories, as per Kowarik's concept of four types of nature in urban areas (Hansen et al., 2017a, pp. 11–12).[8](Hansen et al., 2017a, pp. 11–12)

[8] Simplified characterisation of urban vegetation has led to the description of four types of urban 'nature': nature of the first kind – original natural landscape; nature of the second kind – agricultural and silvicultural cultural landscape; nature of the third kind – symbolic nature of horticultural facilities; nature

- (semi-)natural landscapes such as river courses, wetlands and near-natural forests;
- (agri-)cultural of arable and grasslands, silvicultural landscapes;
- designed green spaces such as parks, allotments, cemeteries;
- novel urban ecosystems, such as succession sites of 'urban wilderness'.

This categorisation does not serve to separate area types but to illustrate the range of possible elements. The transitions between the categories are fluid, and the elements can be assigned multiple times. For example, intentionally preserved or initiated novel urban ecosystems or agriculture elements are also part of designed urban green spaces.

Moreover, search spaces incorporate the entire city's surface, including rooftops and grey and social infrastructures that can be qualified as green infrastructures. If these elements were already examined and incorporated strategically in the context-specific form – for example, as green belts, wedges and accompanying matrices – these structures would represent a suitable starting point for easing the process of identifying and building a green infrastructure network.

Benedict and McMahon suggested building a green infrastructure network based on *hubs, links* and *sites,* mainly drawing on the concept of habitat connectivity (see Figure 9).

> Hubs anchor green infrastructure network and provide space for native plants and animal communities, as well as an origin or destination for wildlife, people and ecological processes moving through the system. (Benedict and McMahon, 2006, p. 13)

Links represent the connections for ecological processes, and sites are considered smaller hubs that are not necessarily physically connected to hubs but that contribute to 'important ecological and social values' (Benedict and McMahon, 2006, p. 14).

With reference to concepts of habitat connectivity, the connection between green infrastructure elements is understood in terms of not only physical continuity but also functional context. For example, the entirety of blue-green rooftops that harvest rainwater and evaporate in a neighbourhood act as in unison and contribute to climate change adaptation. Hence, systematic consideration of all existing and potential green spaces is needed to allow for the development of a 'diverse mosaic of sites with different priority functions and uses' (Hansen et al., 2017a, p. 14).

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of the fourth kind –urban-industrial nature, also described as novel urban ecosystems (Kowarik, 2018, p. 337, 1992).

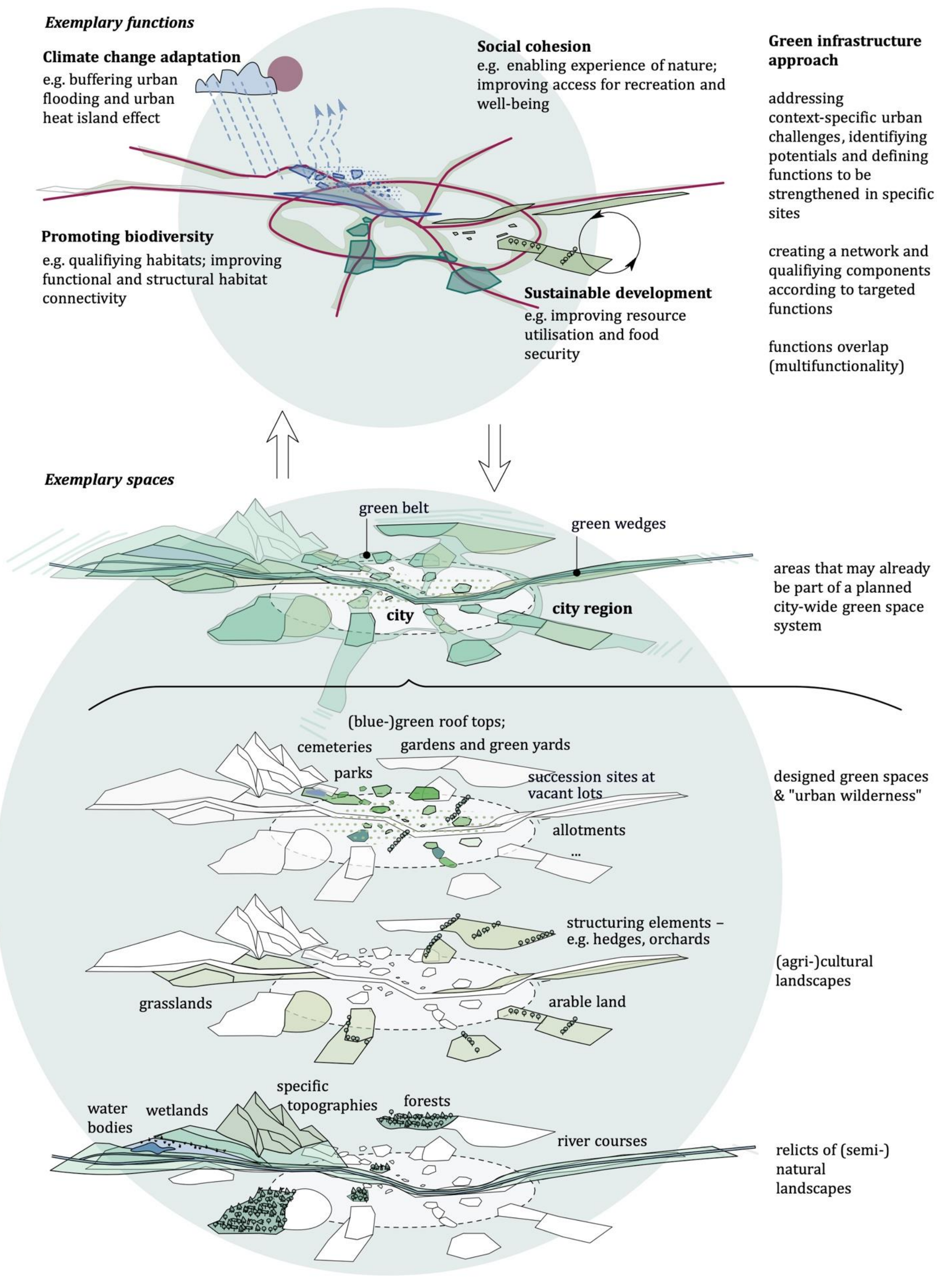

Figure 10 Stylised scheme of the green infrastructure approach and spatial relations

Box 5) Disambiguation of green infrastructure

Definition of green infrastructure

Green infrastructure is a nature-urban-hybrid that forms a continuum from 'green' to 'blue' to 'grey' conventional infrastructure. It is a strategic planning approach that aims to develop networks of green and blue spaces that are designed and managed to enhance ecosystem functioning, thus contributing to the well-being of humans and nonhumans. Due to its integrative, multifunctional approach, green infrastructure planning is capable of addressing a broad range of urban tasks, such as improving metabolic exchange processes between natural and urban systems and resource management, enhancing biodiversity, adapting to climate change, and improving social cohesion. All types of vegetation- and water-related areas and other surfaces of urban areas such as rooftops or facades can become part of the green infrastructure.

Development of green infrastructure

Since the mid-2000s, the concept of green infrastructure has gained remarkable traction, starting in the US and followed by the UK, Europe, Australia and New Zealand (Lennon, 2020; Norman and Alexandra, 2019). Although the approach is new, it emerged from a long history of urban, environmental and landscape planning. The roots of the concept in strategically planning networks of green spaces reach back to the late 19th century, when planners dealt with green space planning on larger scales in the course of urbanisation in the US and Europe. Simultaneous development in different regions has led to regional-specific interpretations and foci of green infrastructure planning that persist even today (Lennon, 2020; Wright, 2011).

United States

Many researchers name Fredrick Law Olmsted as a forerunner of green infrastructure planning. One of his most notable works is the Emerald Necklace Park in Boston, which is designed as a type of interconnected wetland system addressing recreational needs and water management issues (Benedict and McMahon, 2002; Hansen et al., 2018; Lennon, 2020). The US is also considered the origin of the term 'green infrastructure'. An early mention of the term can be found in the President's Council on Sustainable Development report, which lists green infrastructure as one of five strategic areas of community development (PCSD, 1999). The approach was applied for more efficient and sustainable land use and to protect ecosystems as a response to urban sprawl in the 1990s. Instead of sparing 'leftover' green space from uncontrolled urban expansion, green spaces are considered equivalent to buildings and other infrastructures and are thus planned in an integrated and strategic manner (Lennon, 2014). In 2002, Benedict and McMahon published one of the first papers advocating green infrastructure, sparking diffusion of the concept (Benedict and McMahon, 2002). Today, understanding of green infrastructure in the US has a strong emphasis on stormwater management rather than biodiversity and recreation (Hansen et al., 2018; Mell, 2017). The US Environmental Protection Agency (EPA) defines green infrastructure as

> a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits. While single-purpose gray stormwater infrastructure – conventional piped drainage and water treatment systems – is designed to move urban stormwater away from the built environment, green infrastructure reduces and treats stormwater at its source while delivering environmental, social, and economic benefits (US EPA, 2015).

European Union

Early applications of strategically planned green spaces in Europe occurred during rapid urban growth in the 19th century. Berlin had one of the first strategic and spatially concrete planning frameworks for a city-level green space network. The planning framework was developed by Peter Joseph Lenné in 1840 in the course of Berlin's urban extension (Gantioler, 2018; Schöbel, 2007). Another often mentioned early antecedent is the Garden City concept of Ebenezer Howard in the late 19th century. The concept proposed the development of self-contained communities surrounded by greenbelts for recreational and agricultural purposes. Several garden cities were built upon his ideas as new towns (Lennon, 2020; Mell, 2017). For European cities like London ('Metropolitan Green Belt' 1935) or Copenhagen ('Finger Plan', 1947), such strategical green space plans were developed in the 20th century. Initially, the focus was often on serving urban residents' recreational needs, but green structures that were developed during this period later also physically facilitated the concept of 'ecological networks' (Jongman et al., 2004).

Following Benedict and McMahon's influential 2002 paper, the concept of green infrastructure entered European discourse. Within Europe, the UK first adopted the concept in national policy in 2010 (Wright, 2011). In 2013, the European Commission adopted an EU-wide strategy to promote investments in green infrastructure, which contributed to a progressive implementation on the city and national levels in many regions of Europe and a Trans-European Network for Green Infrastructure. The EU strategy's primary goal is to stop and reverse the loss of biodiversity and to enable ecosystems to deliver their many services to people and nature. The strategy is a key factor for the success of the EU 2020 Biodiversity Strategy, which includes establishing green infrastructures and restoring at least 15% of degraded ecosystems. The so-called Natura 2000 network of protected areas (18% of EU land and 6% of EU marine territory) is the backbone of Europe's green infrastructure and is based on the following idea: 'The greater the scale, coherence and connectivity of the green infrastructure network, the greater its benefits' (European Commission, 2019c). Furthermore, the EU Biodiversity Strategy 2030 explicitly names green infrastructure as the central tool to engage with nature as a 'vital ally in the fight against climate change' (European Commission, 2020c, p. 2). The current strategy, with a €20 billion annual budget, also identified urban and peri-urban areas as central fields of action and mandates that every European city of at least 20,000 inhabitants must develop 'Urban Greening Plans'.

The emerging green infrastructure concept enriches the overall discourse on spatial green space planning with its emphasis on infrastructure and systemic understanding of interconnected elements (Thomas and Littlewood, 2010, pp. 14–15). Contemporary guides such as German White Paper 'Green Spaces in the City' do not identify distinct green space figures but do consider the definition of reference values, such as m^2 of green space per capita on certain scales, to support the expansion and connection of green spaces. However, the debate continues as to what extent these reference values can be defined and recommended (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB) et al., 2018, p. 13; WHO, 2016) (see 4.5.2.6).

Asia

To date, the concept of green infrastructure as defined here has not been explicitly picked up in Asian cities. Several approaches and practices in green space planning share common principles with the green infrastructure concept, but these are not systematically applied (Kato, 2011; Rashid, 2018). In some cases, the term green infrastructure is used with a different meaning. Based on an overall focus on 'green growth' and sustainable development in Southeast Asia, green infrastructure is often understood as a means to continue urban and economic growth while minimising environmental risks such as pollution. Projects that are understood as green infrastructure include 'sustainable transport, clean energy, and resilient water systems' (ADB, 2019). In this context, 'green' is not necessarily understood as 'natural or semi-natural' elements but rther as 'clean' or low-emissions elements. However, a recent publication by the Asian Development Bank (ADB) refers to green infrastructure as 'nature based solutions for resilience to climate change adaptation for building better and more liveable Mekong towns' (ADB, 2017, p. 1) and emphasises the need to recognise rehabilitating natural systems in urban areas, which is more in line with understanding in the Anglosphere and the EU.

Transnational conception – Common ground SDGs

The concept of green infrastructure is not explicitly mentioned in current UN frameworks such as the SDGs or the New Urban Agenda. Nevertheless, many planning principles and goals are shared. The goal of ending hunger, achieving food security, improving nutrition and promoting sustainable agriculture (SDG 2) and ensuring healthy lives and promoting well-being (SDG 3) significantly depend on the quality, quantity and accessibility of regional and local green infrastructures. Additionally, goals regarding the sustainable management of resources (SDG 6, 7), building resilient infrastructures (SDG 9) and combatting climate change (SDG 13) have strong links to the concept of green infrastructure. Moreover, the green infrastructure approach can be seen as a tool to achieve the goals of protecting and restoring ecosystems (SDG 15) and providing universal access to green and public spaces (SDG 11.7; (United Nations, 2015). The New Urban Agenda, as operational guidance for cities, shares significant planning principles. Most relevant is commitment No. 67:

> We commit ourselves to promoting the creation and maintenance of well-connected and well distributed networks of open, multipurpose, safe, inclusive, accessible, green and quality public spaces, to improving the resilience of cities to disasters and climate change, including floods, drought risks and heat waves, to improving food security and nutrition, physical and mental health, and household and ambient air quality, to reducing noise and promoting attractive and liveable cities, human settlements and urban landscapes and to prioritizing the conservation of endemic species (United Nations, 2017, p. 19).

Emphasising networks and multifunctionality reflects major principles of the green infrastructure approach.

3.6 Productive green infrastructure (PGI)

In recent years, the intersection of urban food systems and green infrastructure planning has produced lively discourse and new concepts and terms, including 'edible green infrastructure' (Russo et al., 2017), 'Continuous Productive Urban Landscape' (Viljoen et al., 2005) and 'green-agro infrastructure' (Quaglia and Geissler, 2018). The megacity research project 'Urban Agriculture as an Integrative Factor of Climate-Optimised Urban Development, Casablanca / Morocco' (2008-2013) funded by the German Federal Ministry for Education and Research (BMBF) was the first to introduce the term 'productive green infrastructure' (Giseke et al., 2015c).

According to the European Commission, a range of different green spaces can be part of green infrastructure under the condition that they deliver multiple ecosystem services (see 3.5.1). 'Gardens' and 'low-intensity agricultural areas' are considered a possible component of green infrastructure, while 'multifunctional resilient agriculture and forestry' is considered a green infrastructure *benefit* along with features like enhancing pollination and pest control (European Commission, 2013c). Urban agriculture is not mentioned explicitly.

The research project 'Urban Agriculture as an Integrative Factor of Climate-Optimised Urban Development, Casablanca / Morocco' understands urban agriculture as a 'hybrid, network-generating infrastructure capable of intermediating reciprocal processes between the urban, rural and natural spheres. Related infrastructural systems such as the urban water or waste systems are constitutive hybrid elements within this context as well' (Giseke et al., 2015e, p. 304). Consequently, urban agriculture is conceptualised as a type of PGI that is an extension of the green infrastructure concept. The project underscored the metabolic and spatial interconnectivity of urban and rural spheres, and it considered the concept of green infrastructure helpful as it overcomes the dichotomy of natural and artificially created open spaces and endorses a network that physically connects rural areas with dense urban cores. One principle of green infrastructure is multifunctionality in diversifying functions and functioning within spatially defined units. Hence, urban agriculture is considered one of multiple layers of the green space system. The Casablanca project has a broad understanding of PGI, which also includes more intensive typologies such as 'Hyper-productive Rural Landscapes'(Giseke et al., 2015d) (for more description of envisioned typologies, see 3.3.4).

Similarly, Lin et al. deemed the entirety of urban agriculture as a PGI (Lin et al., 2017). Urban agricultural systems 'can be productive features of cities, providing important environmental and social services that benefit and support urban communities' (Lin et al., 2017, p. 155). Expanding and developing urban agriculture as a PGI requires further strategies to maximise these benefits. Russo et al. limited their understanding of 'edible green infrastructure' to sustainable land use practices that 'yield food, while protecting the environment and its associating human communities' (Russo et al., 2017, p. 54), thus meeting green infrastructure's principles of sustainable land use and the protection/enhancement of biodiversity. Skar et al. referred to the former work of Timpe et al. and clarified that urban agriculture needs to adopt sustainable farming practices and safeguard biodiversity. They connected urban agriculture and green infrastructure through common benefits and ecosystem services. They declared that 'urban agriculture contributes to the ecosystem services of green infrastructure' (Skar et al., 2020, p. 5; Timpe, Axel et al., 2015). For example, the EU describes 'multifunctional resilient agriculture and forestry' as a green infrastructure benefit that urban agriculture contributes to by providing food, fibre, and biomass. Another green infrastructure benefit is 'health and well-being', which urban agriculture contributes to through farm work and gardening activities for physical and mental health and access to healthy local food.

However, Russo et al. stresses that urban agriculture is rarely integrated as part of green infrastructure or ecosystem service frameworks because the emphasis of most green infrastructure plans lies on regulatory (e.g., climate change adaptation), cultural (e.g., recreation) and supporting (enhancing biodiversity) services instead of provisioning services (Russo et al., 2017), which are among the key features of urban agriculture. For instance, a review from South Africa demonstrated that provisioning services were promoted in developing or rural areas, while urban residential gardens tended to be 'Westernised' and to have limited food production practices (Breed et al., 2015). In the reality of many developing and newly industrialised countries, green spaces significantly consist of urban agriculture (Smit et al., 2001c; van Leeuwen et al., 2010). Two recent studies – one in Argentina, one in in Burkina Faso – on the effects of urban green areas on temperature highlight the importance of preserving urban agriculture areas in terms of climate change mitigation (Coronel et al., 2015; Di Leo et al., 2016).

From the perspective of urban food system planning, PGI belongs to one section of the food value chain: production, and precisely that which takes place in the city region in the form of urban or peri-urban agriculture. Urban agriculture drives food planning processes and is a key component of integrating urban planning and food systems (Cabannes and Marocchino, 2018). Urban agriculture comprises a variety of cultivation techniques, some of which are based on soil-less (e.g., hydroponics, aquaponics) or building-integrated production (see 3.3.3.2). The latter has limited capacities in enhancing biodiversity and balancing the urban water cycle. Hence, in the narrower sense, units that are outdoors and soil-based are more aligned with this dissertation's understanding of a PGI.

3.7 Summary and conclusion

This chapter illustrated conceptual approaches and guiding principles that offer new perspectives regarding exchange processes between urban and natural systems. The approach of *urban metabolism* (3.1) has gained popularity as it addresses the metabolic interdependency of urban and natural systems, viewing cities as *urban ecosystems.* Assessing material and energy flows is the basis for detecting paths for optimisation of resource management and alleviation of environmental degradation by mimicking cycling in natural ecosystems (see 2.4). Urban metabolism is shaped by *environmental* conditions and nutrient, water or carbon cycles as well as the *social sphere of humanity* through governance and economics. Nature and humanity are metabolically interconnected by a 'socio-spatial fabric' *that* 'privileges some and excludes many' (Swyngedouw, 2006, p. 118). In this sense, an urban metabolism is subject to societal and political negotiation processes. Transformative and holistic planning and participatory governance are needed for optimised resource management practices.

Acknowledging metabolic interdependency requires a new approach to identifying and dealing with natural systems embedded in the urban, which is what the planning approaches of *urban food system planning* (3.2) and *green infrastructure planning* (3.5) aim at.

The *urban food system* evolved through social-ecological systems between the technosphere and the biosphere to reach the single sphere of the urban metabolism. Urban food systems have been identified as a particular driver of human-induced planetary alterations as well as a critical and potentially vulnerable infrastructure in urbanising regions (Cesari et al., 2016; FAO and WHO, 2019; Jennings et al., 2015). For this reason, food has reappeared on the agenda of urban planning (Morgan and Rachel Santo, 2018; Pothukuchi and Kaufman, 2000).

This dissertation concentrates on the physical appearance of productive units of the urban food system that are part of cities' green space networks. These productive units have long been conceptualised in the parallel discourse of *urban agriculture* and are deemed essential to rendering cities more sustainable. In addition to food production, they contribute to urban residents' livelihood in many ways and capture nutrients and water from the urban metabolism that otherwise are likely to pollute rivers and coastal waters (Girardet, 2005; Skar et al., 2020; Zeunert, 2018). Urban agriculture physically shapes the urban environment and is a central field at the intersection of urban food systems and urban planning. Various researchers have identified structural features to build typologies across spatial, technological and socio-economic dimensions, which helps to operationalise urban agriculture in urban planning (Giseke et al., 2015c; Lovell, 2010; for example Smit et al., 2001a). Most typology classifications are situated along an urban-rural gradient and consider typical geographic conditions and qualities such as slopes, vicinity to water bodies and dense urban surfaces (e.g., rooftops or porches), which helps to localise elements of urban agriculture.

Based on the insights of the urban metabolism and urban food systems, the role of infrastructures cannot be overestimated (3.4). Infrastructures have always been conceived as the foundation of the economy and basic urban services, and they facilitate resource flows, thus fundamentally shaping the urban metabolism (Allen, 1999; Jochimsen, 1966). Along with various urbanisation processes, infrastructure development is at different stages in the Global North and the Global South. The modernist city's paradigm has generated centralised, large-scale infrastructure systems that conveniently manage bodily functions and separate and hide adherent metabolic processes, which conflicts with the current paradigm of sustainable urban metabolism aiming at circular flows (Bélanger, 2017; Gandy, 2005). Moreover, their extended networks, often managed by transnational organisations, and their high initial investment costs give them a kind of resistant character and momentum, which hinder adjustment and transformation (Kropp, 2018).

For this reason, infrastructure development has been rediscovered by professionals such as designers and architects as a 'series of interconnecting life support systems' (Gandy, 2005, p. 28), a 'great enabler, the glue of urbanisation' (Bélanger, 2017, p. 437) and the 'actual frontier' (Joachim and Fessel, 2013, p. 270) of reformation. Regarding rapid urbanisation in the Global South, leapfrogging towards alternative infrastructure systems has been conceptualised in sustainable transition theory (Binz and Truffer, 2009). Across all sectors, a decentralisation of systems that are more flexible and adaptable that intend to produce smaller and potentially circular loops in resource management is discussed. This approach also entails a decentralisation of responsibilities and increased participation by a greater variety of stakeholders (Capodaglio, 2017; Prytula, 2011; Wiskerke, 2015). These tendencies also anticipate more proactive involvement of natural systems in the process of resource exchanges and urban development. While infrastructural urbanism metaphorically assigned ecological functioning to infrastructures (Allen, 1999, p. 57) due to their ability to manage flows but referred to regular 'hard' infrastructures (e.g., roads, pipes), current discourses endorse 'soft, leaner infrastructures' (Bélanger, 2017, p. 447) that are composed of 'living networks of the biosphere' (Perrotti, 2015, p. 72).

Green infrastructure (3.5) corresponds to these requirements, building on the acknowledgment of interdependent human and ecosystem health. The term refers to a strategic planning approach to qualify and interconnect various types of green spaces and render them part of a green infrastructure network, which is inevitable for the functioning of urban areas, just like other infrastructures (Benedict and McMahon, 2002; European Commission, 2013a; Hansen et al., 2018). This visible and tangible type of infrastructure substantially determines the atmosphere and quality of life in cities, providing numerous opportunities for participatory management and design (Hansen et al., 2017b). Besides contributing to human health, green infrastructure planning is a means of preserving and enhancing diversity within ecosystems regarding habitats, species and genes (Tzoulas et al., 2007). Moreover, the network of functionally or spatially connected entities contributes to decentralised, tightened resource loops, especially in the form of *urban agriculture* (Skar et al., 2020; Wiskerke, 2015), by intersecting with the planning approach of urban food systems.

In recent years, different planning concepts at the intersection of urban food systems and green infrastructure planning have emerged, highlighting the role of urban agriculture as a type of productive green infrastructure. The term was first introduced in the research project 'Urban Agriculture as an Integrative Factor of Climate-Optimised Urban Development, Casablanca / Morocco' (2008-2013), where it was more or less equated with urban agriculture in its various forms (Giseke et al., 2015c). To date, green infrastructure planning is more prevalent in regions of the Global North, where its provisioning function and urban agriculture are often not the focus in arguments (Russo et al., 2017). Meanwhile, in many regions of the Global South, existing green spaces host urban agriculture, but green infrastructure assessment and planning has often not been adopted and urban agriculture practices remain informal (Smit et al., 2001c; van Leeuwen et al., 2010).

PART II DERIVATION OF CONCEPTUAL APPROACH

4 PRODUCTIVE GREEN INFRASTRUCTURE (PGI)

In this thesis, productive green infrastructure (PGI) is understood as a further development of the current green infrastructure concept focussing on urban agriculture and its spatial layout and associated material flows. The PGI approach links to the urban food system and urban metabolism discourse and highlights urban agriculture's functioning within the urban system.

This chapter outlines the understanding of PGI within this thesis (4.1), followed by presenting PGI's potential benefits and functioning as a type of infrastructure that provides for urban residents (including humans and nonhumans) in terms of sustainable urban metabolism (4.2). Potential disservices and pathways to avoid these are also described (4.3). Selected contemporary approaches that operationalise urban food system or green infrastructure planning are elaborated to gain an overview of scopes and procedures (4.4). Section 4.5 delves into assessment examples to produce an overview of procedures. The challenges of planning PGI are identified abductively (4.6), followed by a summary and conclusion (4.7).

4.1 Definition of PGI

4.1.1 Definition

The concepts of systemically planning a network of *green infrastructure* (see 3.5) and assessing and enhancing the city's *urban food system* (see 3.2) have a common ground: a systemic understanding of the interaction between cities and their environment as they intersect in the physical sphere of PGI.

By referring to *infrastructure* which can be defined as a 'prerequisite for the production, distribution and use of goods and services' (Jochimsen, 1966), the green infrastructure concept establishes that green space systems are of structural importance to the basic supply character of city regions. At the same time, the approach lends mutual value to natural systems by aiming at preserving, respectively developing multifunctional green spaces systems in urban areas as part of a sustainable urban development. Green infrastructure is understood as a continuum from green to conventional/grey infrastructures that physically connects natural and urban systems and their exchange processes (Pellegrino et al., 2015) in a 'natural life support system' for people as well as wildlife (Benedict and McMahon, 2006, p. 1). The significance of green infrastructure is also evident through urban agriculture and its abilities to generate food and make use of urban 'metabolites' (Zhang, 2013) such as accruing organic waste and greywater,[9] thus optimising the urban metabolism by tightening the cycles of nutrition and water. Urban agriculture is a key area of urban food system planning, but it often represents a blind spot in spatial planning due to its dispersed spatial structure and informal character. Hence, the green infrastructure approach could be a suitable vehicle for the systematic assessment and careful planning of urban agriculture.

The aim of this work is to contribute to the conceptualisation of PGI and assessing and operationalizing dispersed and informal elements of urban agriculture as part of a strategically planned green space network. In this sense, PGI is a specific element of green infrastructure. The following chapter is oriented around green infrastructure's key principles, as defined in the course of the EU-wide research project GREEN SURGE (Hansen et al., 2017b) (see also 4.4.1):

Key principle of green infrastructure	**Connotation of PGI in the framework of green infrastructure**
Green-grey integration – combining green and grey infrastructures	PGI is developed in a way that aligns with other urban infrastructure and aims to optimise urban metabolism. Urban agriculture can be linked with water and waste infrastructure to utilise collected nutrients and water.
Connectivity – creating green space networks	Incorporating PGI expands the search space for potential elements and can create linkages by, for example, securing community gardens as part of a larger greenspace network and improving their specific functions in this system.

[9] Greywater is less polluted wastewater from domestic sources, excluding human waste. It comprises outflows of washing machines, dishwashers, and bathtubs (Gorgich et al., 2020).

Multifunctionality – delivering and enhancing multiple functions and services	PGI emphasises provisioning functions in terms of improving access to fresh produce, thereby sustaining more established supporting, regulating, and cultural services.
Social inclusion – collaborative and participatory planning	PGI as a cultivated type of green infrastructure thrives on the commitment of a broad variety and number of stakeholders, primarily comprised of civil stakeholders.

Within the green infrastructure framework, PGI highlights the role of productive green spaces as a multifunctional open space, with a particular emphasis on metabolic processes related to the urban food system and the overall urban metabolism. Thus, the benefits and arguments for implementing an urban food system and green infrastructure are linked.

The following graphic illustrates basic principles of this definition (Figure 11).

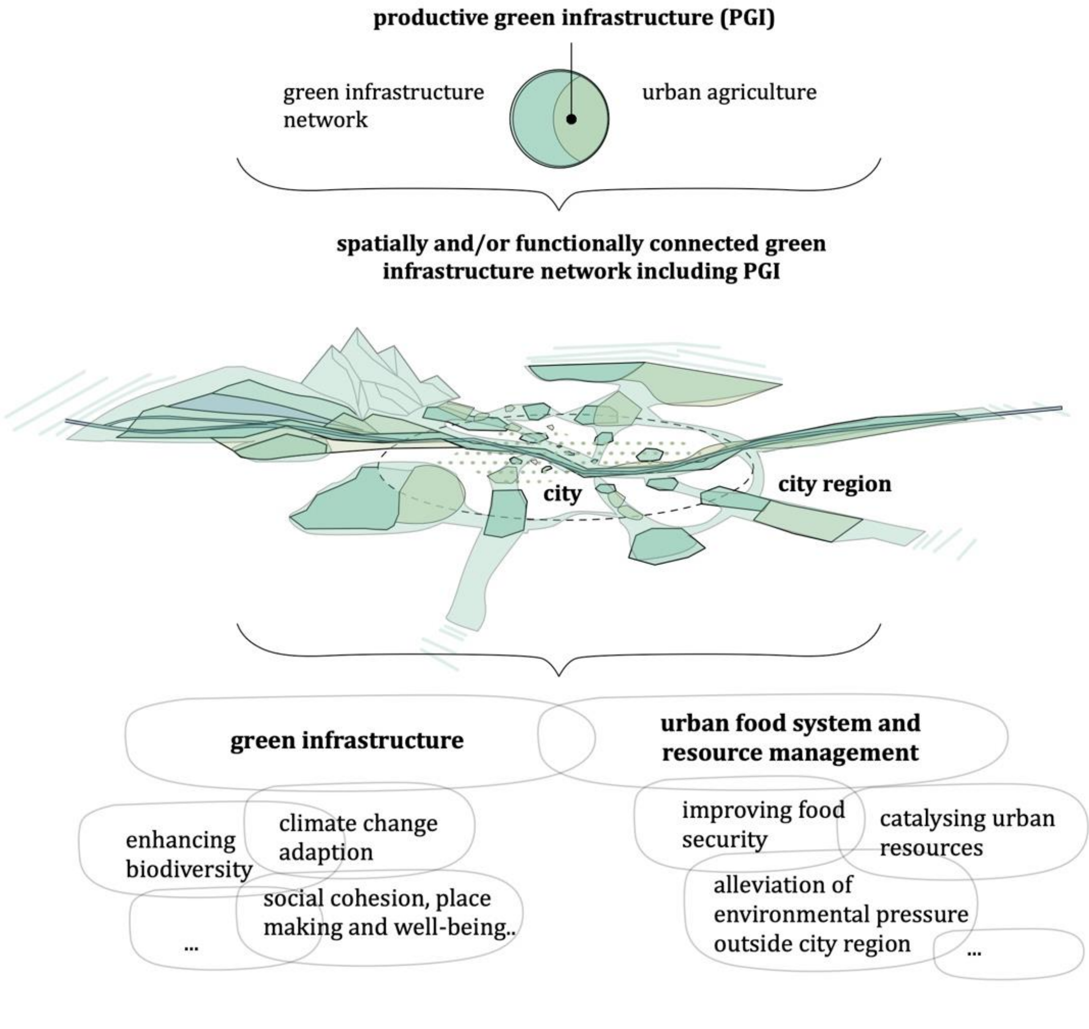

Figure 11 Definition of productive green infrastructure (PGI)

4.1.2 Emphasis on PGI in the context of rapidly growing regions in the Global South

While urban agriculture is generally conceived as a potential element of green infrastructure, it is often underrepresented in planning concepts (see 3.6). This research anticipates that green infrastructure planning with an emphasis on PGI is particularly relevant in the context of rapidly growing regions in the Global South for the following reasons:

a) rapid urbanisation places especial pressure on existing elements of a potential green infrastructure.
b) in many regions of the Global South, potential green infrastructure often consists largely of urban agriculture (3.3.2).
c) rapid urban growth processes potentially provide options for new infrastructure systems in which PGI can play a major role.

In this context, green infrastructure could be used as a strategic spatial planning approach for different types of green spaces, including urban agriculture, by promoting the principle of multifunctionality and hence the integration of different land uses and functions, including food production and closing resource loops as well as climate change mitigation, enhancement of biodiversity and social cohesion (Skar et al., 2020)

Combining the approaches of green infrastructure and urban agriculture as part of the urban food system targets critical infrastructure issues that are essential for the functioning of society and the economy beyond disciplinary and administrative territories (Giseke et al., 2015a; Russo et al., 2017).

4.1.3 PGI for an optimised urban metabolism

This study assumes that PGI can contribute to *optimising a city region's urban metabolism* for increased sustainability by circularising resource flows (3.1.4). The basic principles of PGI's potential contributions in the context of other infrastructure systems are captured in the following schema of two urban scenarios and their simplified urban metabolism (see Figure 12).

Within the spatial dimension, the first scenario is characterised by linear input-output flows in which wastes accumulate at places conceptualised as 'outside' the city. The second scenario incorporates a form of PGI that contributes to circularly organised flows within the metabolism in terms of tightening nutrient cycles by exploiting resources from wastes and wastewater, which therefore have a less externalized and more natural water cycle, thus mitigating urban flooding and urban heat island effects through infiltration and evaporation.

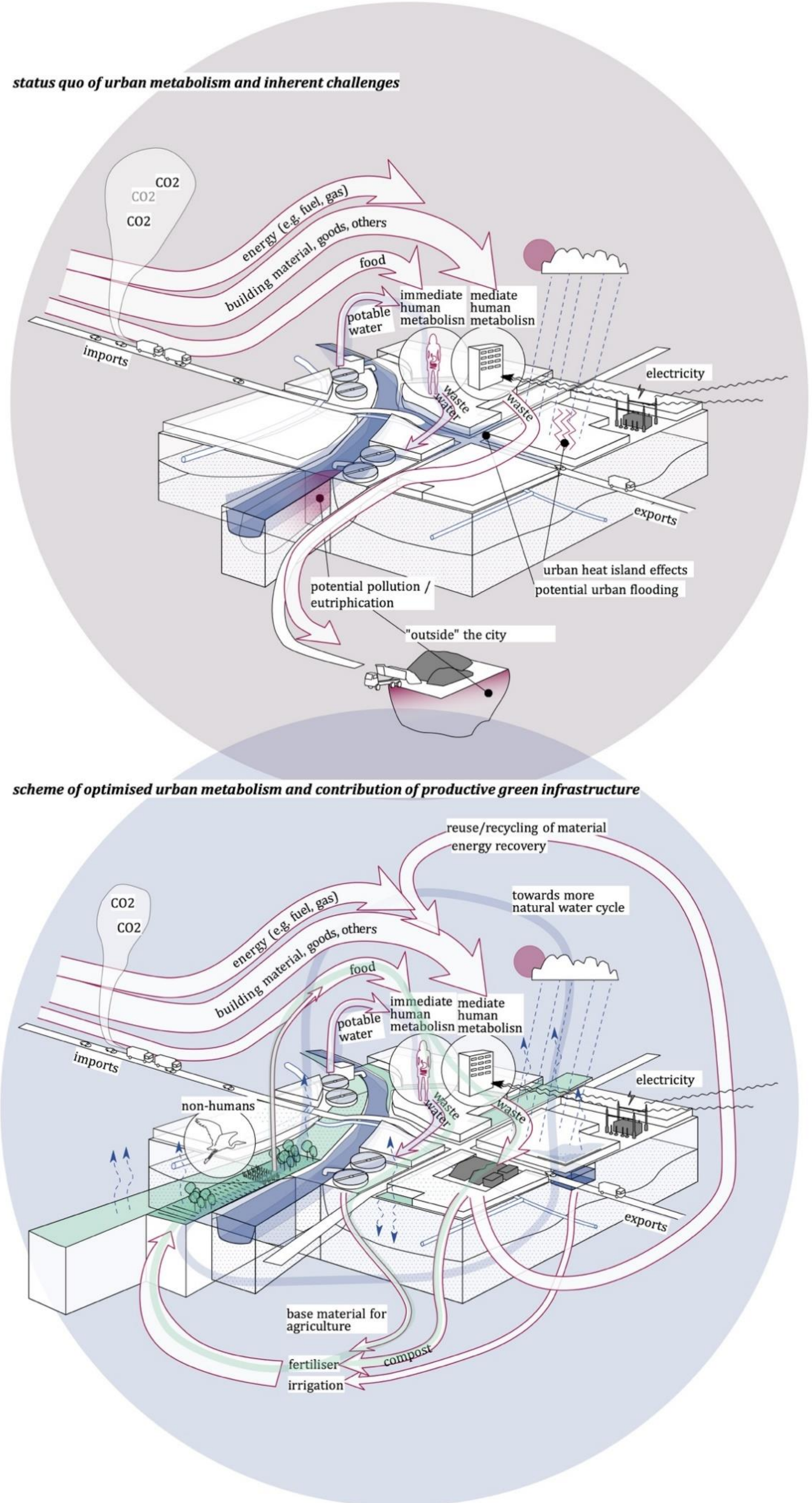

Figure 12 Scheme of optimised urban metabolism and contribution of PGI

4.2 Potential benefits of PGI and its infrastructure functioning

4.2.1 Overview of potential benefits

Green infrastructure planning endorses the well-being of humans, nonhumans (e.g., any other type of species) and ecosystems (Tzoulas et al., 2007). It is closely connected to the concept of ecosystem services, which describes the multitude of direct and indirect contributions to well-being in regard to economic, material, health, or psychological benefits (Naturkapital Deutschland – TEEB DE et al., 2016; TEEB, 2010) (see also 3.5.1). Mutual benefits between the planning of green infrastructure and optimisation of urban food systems are often mentioned by scholars. For instance, the German national strategy for planning urban green infrastructure repeatedly mentions the role of productive green spaces in resource efficiency and social cohesion (Hansen et al., 2018).

Similarly, strategies for enhancing regional and urban food production advocate urban agriculture's benefits in the form of multifunctional productive green spaces. Potential benefits range from increased resource efficiency if taking advantage of the close proximity of resources and consumers to ecological functions (e.g., biodiversity, nutrient cycling) and cultural functions (e.g., recreation, cultural heritage, and visual quality; (Lovell, 2010; van Leeuwen et al., 2010).

In both approaches, the ability of productive green spaces to mitigate climate-change-related risks such as urban heat island effects and urban flooding are among the most convincing co-benefits, underlining the necessity for green spaces in urban environments and resilient and sustainable urban development overall (Hansen et al., 2018; Wiskerke, 2015).

The following table gives an overview of PGI's potential contributions to urban residents' well-being and to the sustainability and resilience of city regions. The potential benefits are roughly structured along interconnected thematic dimensions and distinguish between improving food flows and increasing the quality and quantity of green spaces.

Table 1 Potential benefits of PGI in the context of the food system and green infrastructure planning with exemplary references

	Aspects related to an increased share of regional produce through **urban food system** planning	Aspects related to increased quantity and quality of interconnected green spaces through **green infrastructure** planning
Health and well-being of humans	• Increased food security (Zezza and Tasciotti, 2010) • Increased knowledge about food and nutrition amongst urban dwellers that results in healthier diets and increased availability of and access to nutritious food (Jennings et al., 2015)	• Availability of high-quality urban green spaces in the living environment contributes to mental, physical, and social well-being. A recent WHO report (WHO, 2016) identified the following pathways for urban green and human well-being and health: relaxation and restoration, fostering social interaction, improved functioning of the immune system, enhanced physical activity, improved fitness, and reduced obesity, anthropogenic noise buffering, production of natural sounds, reduced exposure to air pollution, reduction of the urban heat island effect, optimised exposure to sunlight, and improved sleep • Experience of nature (Amat et al., 2020; Beatley and Newman, 2013) and enrichment of the microbiome through contact with diverse ecosystems (Mills et al., 2017) are integral vectors for this mental and physical well-being
Health and well-being of nonhumans	• Potentially lower externalised biodiversity footprint depending on the share of regional produce and sustainability of human diets (Wilting et al., 2017) • Greater availability of limited resources such as water in dry regions and reduction of ozone and wind and increased temperature in cities of moderate climate can lead	• Increased local agroecological diversity (Dietrich, 2014) • Promotion of diverse (extensive) urban green structures that cover diverse habitat requirements for animal and plant species and improvement of habitat connectivity (Tzoulas et al., 2007)

	to higher productivity. Species richness initially increases along higher productivity but declines at a certain height; hence, irrigated and appropriately fertilised patches can potentially enhance biodiversity (Faeth et al., 2011)	
Social inclusion	• Increased involvement of urban residents in producing food for self-supply, in participative formats of co-producing, or through a relationship to local producers enhances a local food culture, social exchange and cohesion (Lovell, 2010; van Leeuwen et al., 2010) • Food culture knowledge creation regarding the cultivation and preparation of food as well as nutrition and resource utilisation (Jennings et al., 2015)	• Physically enables exchange between different social groups and promotes personal contacts and social networks and increases the sense of community (Gantioler, 2018) • Participative maintenance of public space creates places of encounter and integration and increases identification of residents with their neighbourhood (Andersson et al., 2014; Naturkapital Deutschland – TEEB DE et al., 2016) • Environmental education through experiences of nature, e.g., securing and creating new spaces such as school gardens, community gardens, allotment gardens, and urban wilderness (Hansen et al., 2018)
Climate change adaptation	• Increased resilience against bottlenecks of resources such as water by enabling more efficient resource flows on a smaller scale (Skar et al., 2020; Wiskerke, 2015)	• Development of intra-urban, small-scale, closely-meshed and richly structured open-space systems, in combination with open fresh-air corridors, achieves a bioclimatic effect throughout the city (Naturkapital Deutschland – TEEB DE et al., 2016) • Improving urban water cycles to mitigate the urban heat island effect and urban flooding by increasing water infiltration capacity in urban areas and reducing surface runoff, thus enhancing evaporative cooling (Thorne et al., 2018) • Increasing the proportion of shade-giving green structures in order to reduce heat exposure due to shading and evaporative cooling (Pramova et al., 2012)
Resource efficiency	• Potentially lower transportation expenditure and greenhouse gas emissions depending on local context (Lee et al., 2015) • Reduced food waste and loss (Jennings et al., 2015) • Tightening local nutrient and water cycles (Smit and Nasr, 1992; Wiskerke, 2015)	• Carbon sink through binding in plants and soil of green spaces (Naturkapital Deutschland – TEEB DE et al., 2016) • Well-connected green spaces equipped with cycling infrastructure encourages resource-efficient mobility (Hansen, 2018)
Economic aspects	• Increased resilience against sudden interruptions in global food supply chains (Lang, 2010) • Reduced food prices for urban consumers and increased livelihood resilience for small-scale producers, economic vitality, innovation (Jennings et al., 2015)	• Promotion of the greening of cities strengthens attractivity for residents, tourists and businesses (Naturkapital Deutschland – TEEB DE et al., 2016) • Use of nature-based solutions as a cost-effective alternative to conventional technical infrastructure, particularly regarding blue-green infrastructure (Cohen-Shacham et al., 2016)

4.2.2 PGI as an urban infrastructure that shapes the urban metabolism

A major aspect of green infrastructure planning is its emphasis on *infrastructure*, indicating its indispensability in urban areas by providing for urban residents' needs, including both human (4.2.2.1) and nonhuman actors (4.2.2.2). PGI builds its own *'soft'* and *'living'* infrastructure (Bélanger, 2017; Perrotti, 2015) but also supplements other 'hard' infrastructure systems such as the water and wastewater systems and the social infrastructure, as illustrated in Figure 13.

4.2.2.1 Human well-being

By catalysing urban resources and contributing to rendering nutrient and water flows more stable and sustainable alongside other supply and disposal infrastructures (e.g., water, wastewater, solid waste, energy), PGI adds to satisfying the basic human needs[10] of nutrition, water supply and sanitation. These needs are considered physiological needs of the human metabolism and are understood as basal flows, which is a counterpart to advanced societal flows within the discourse of urban metabolism (Fischer-Kowalski et al., 1997) (see also 3.1.3). At the same time, 'Basic societal relations to nature' are considered among the core basic needs[11] within social-ecological systems as these relations are indispensable to societal life (Becker, 2012, p. 6).

As PGI is a decentralised type of infrastructure that is brought to life by many individual stakeholders, including professional farmers and citizens growing their own food, providing *opportunities* to engage in creating and cultivating PGI expands people's *choices*[12] for living a long and healthy life (see 3.1.4.2). Choices are also expanded by making safe, nutritious, and sustainable food easily accessible.

PGI plays a vital role in terms of supporting the functioning of social infrastructures. Healthcare has an overarching function in this context since all aspects of well-being are ultimately facets of preventive healthcare. By motivating people to spend time in public, cultivate plants, 'dig in the soil', walk or cycle outside, PGI directly enhances people's fitness and well-being through relaxation and restoration, fostering social interaction, improving the functioning of the immune system, enhancing physical activity, and reducing obesity (Beatley and Newman, 2013; Naturkapital Deutschland – TEEB DE et al., 2016; Soga and Gaston, 2016; WHO, 2016) (see also negative health impact of mismanaged food systems 2.3.3). Moreover, PGI contributes to environmental education and job creation, particularly through urban agriculture (Jennings et al., 2015; van Leeuwen et al., 2010).

Urban residents' needs also include the containment of harmful substances through potential pollution, thus mitigating major health risks due to climate change and related weather extremes. In particular, heat stress and urban flooding are increasingly threatening urban phenomena (see 2.2.1.2). PGI in the form of blue-green infrastructure has been acknowledged as playing a vital role in mitigating these risks in current urban planning processes (see 3.5.2).

4.2.2.2 Well-being of other species

Biodiversity is one of the cornerstones of the ecosystem functioning and has been recognised as humanity's 'life insurance' (European Commission, 2011, p. 1). Biodiversity declines at a rapid speed (WWF et al., 2018, p. 7) (see 2.2.2).

Current discourse regarding the interdependency between urban and natural systems was described in section 2.4. This insight, amplified by the COVID-19 pandemic, raises questions about how humans co-exist with nonhumans (Giseke, 2020). Political philosopher Bruno Latour has long called for collectives consisting of 'associations of humans and nonhumans' (Latour, 2004, p. 70). Haraway advocates 'making kin with other species' to 'make the Anthropocene as short/thin as possible and to cultivate with each other in every way imaginable epochs to come that can replenish refuge'[13] (Haraway, 2016, p. 100). Tsing argues that sustainability in the sense of passing a liveable Earth to future generations of humans and nonhumans has only been possible in the past because humans have 'aligned themselves with the dynamics of multispecies resurgence' (Tsing, 2017, p. 51).

Enhancing biodiversity has gained attention in urban planning and landscape architecture for multiple reasons. First, fast rates of biodiversity loss cannot be countered by conservation of near-natural areas alone. Biodiversity has to be proactively strengthened at every opportunity, including via urban

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[10] The basic human needs were widely approved in the late 1970s and have recently been rediscovered (Caprotti, 2018; Jolly et al., 2009; Rudra, 2009; Watson, 2014). These needs are most often defined as nutrition, water supply and sanitation, health, shelter, and education.

[11] The Resilience Alliance defines basic core needs as work and production, sexuality and reproduction, nutrition, and water supply, mobility and housing, and basic societal relations to nature (Becker, 2012, p. 6).

[12] Expanding choices and opportunities are a current core aim of human development for the United Nations (United Nations Development Programme, 2020).

[13] This refers to Tsing's observation that the Anthropocene could lead to the destruction of refugia from which diverse species can be reconstituted after major events such as desertification.

development (Naturkapital Deutschland – TEEB DE et al., 2016). This insight has entered policy through the current EU Biodiversity strategy 2030, which promotes 'greening of urban and peri-urban areas' as one of 10 overall goals under the objective of 'Bringing nature back into our lives' (European Commission, 2020c, p. 12). Additionally, research on positive physical and mental health benefits due to experiencing nature is growing. The concept of 'Biophilia' has had a revival after its initial popularisation by socio-biologist E.O. Wilson (Wilson, 1984). The term refers to humans' need to connect with nature. Myriad studies have indicated that people with greater exposure to diverse green spaces are likely to live longer and benefit from positive effects on their mood and cognitive performance (Amat et al., 2020; Beatley and Newman, 2013) (see also 2.2.2).

In urban areas, the abundance and richness of species are mainly determined by green spaces' characteristics and the selection and maintenance of plant communities. Plants provide the resource base and habitat structure for the biological community, which includes birds, mammals, reptiles, invertebrates, and soil microbiota (Faeth et al., 2011). Hence, green infrastructure has been posited as potentially preserving and enhancing diversity within ecosystems in terms of habitats, species and genes, thus strengthening ecosystemic health (Tzoulas et al., 2007). The needs of specific animals depend on the lifecycle of individual species. Essential needs include the availability of specific food sources and shelter, such as nesting sites and protection from predation (Weisser and Hauck, 2017). Additional integration of particular habitat features to attract selected species has been included in the *Animal-Aided Design approach* developed at Technical University München and University of Kassel in Germany. Adding these features to the urban environment enriches the design and atmosphere for humans as well (Hauck and Weisser, 2015; Weisser and Hauck, 2017) (see also 2.2.2).

The metabolism of human and nonhuman species overlaps in the holobiont concept. Humans and other species host and depend on a variety of microorganisms. Recent studies have suggested that exposure to biodiverse environments benefits human health through symbiotic microbiota (Mills et al., 2019).

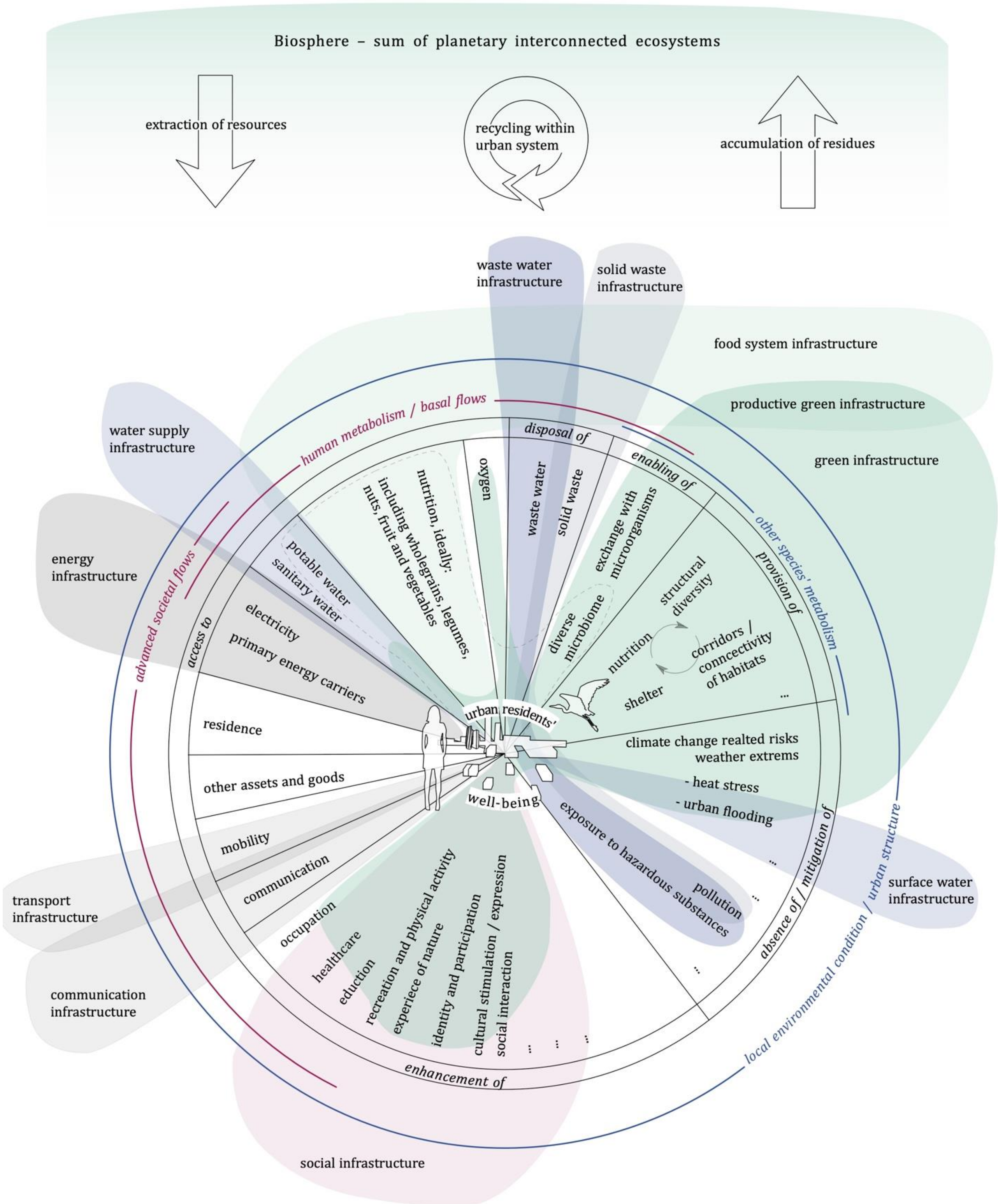


Figure 13 Aspects relevant to urban residents' well-being and relation to infrastructure systems

4.3 Potential disadvantages of PGI

Beyond the multitude of benefits, potential disadvantages of PGI and solutions to avoid these are briefly discussed in the following sub-sections.

4.3.1 Risks to human health

A frequent argument against urban agriculture is the potential contamination of produce due to urban pollution (Brown et al., 2016). While the reduction of air pollution is a benefit of green infrastructure (Rittel et al., 2014), pollution absorption can be critical in food production. Air pollutants are deposited in the ground and can cause acidification, salinisation and high heavy metals concentrations (Skar et al., 2020), affecting plants and produce. Heavy concentrations of metals such as lead have been found to vary according to season and rainfall, with more rainfall diluting the concentration (Soriano et al., 2012). Regarding pollution at roadsides through traffic, heavy metal concentration has been observed to decrease with increasing soil depth and distance to the road, with the highest load within 5 m of the road (Werkenthin et al., 2014). Other areas with higher risks include waterways with unregulated wastewater discharges downstream from polluted areas and waste dumps (Smit, 2001). Various studies in the US, the Netherlands and Zambia have tested urban agricultural soils, including soils which were irrigated with treated wastewater, and found that lead levels in the blood of consumers were not higher than average and were in accordance with health standards (Smit, 2001). A more recent study also reviewed the potential of lead exposure through direct (soil contact) and indirect pathways (digestion of food grown on soils with elevated lead levels). It confirmed that urban agriculture is highly unlikely to increase lead levels in the blood (Brown et al., 2016). Overall, potential contamination should be taken seriously, but its risks do not support an argument against urban agriculture. The suitability of the soil of a site and the quality of treated wastewater for irrigation must be checked on-site.

Moreover, as the current COVID-19 pandemic illustrates, improper animal husbandry and trading can pose health threats through disease transmission. In addition, crop production can be problematic. For instance, poor composting techniques can attract rats, and standing water for irrigation can increase mosquitos and related diseases such as malaria (Smit, 2001).

4.3.2 Ecological impact through improper cultivation techniques

Eutrophication and acidification of ecosystems are some of the greatest threats of human-induced planetary alterations, as described in this dissertation's opening (see 2.1). Unsustainable management practices such as nutrient mining, erosion, and surface and groundwater pollution from improper use of fertilisers and pesticides erode ecosystem functioning and lower long-term production capacity (FAO, 2013; Fischer-Kowalski and Haberl, 1993, p.; Haber, 2016) (see 2.3.2). Overly intensive plant cultivation with excessive use of pesticides, extensive pruning and mowing can limit the capacity of productive green spaces to host wildlife such as insects (Faeth et al., 2011; Lin et al., 2017) and is not compatible with green infrastructure's principle of enhancing biodiversity (see 3.5.1). Moreover, chemicals, pesticides and invasive non-indigenous species can be introduced to neighbouring green spaces (Lin et al., 2017). Improper techniques are more prevalent in regions where urban agriculture is not formalised and regulatory policies are not enforced. The fear of being evicted leads urban farmers to overuse chemical fertiliser and to not invest in mid- to long-term soil fertility, causing silting and pollution of groundwater (Bryld, 2003). Misuses of chemical fertiliser and pesticides can also affect human well-being and result from a lack of education (Smit, 2001).

4.3.3 Addressing the disadvantages

> Safe food from urban agriculture begins with educating the farmer at the community level and providing her or him with an extension service and technical assistance that enables safe practices. (Smit, 2001, p. 17)

To maintain the health of both humans and ecosystems, proper cultivation and green space management practices need to be applied. Urban farmers' engagement can help to share the urban administration's responsibility for maintaining and cultivating green spaces properly. Most urban farmers live in close vicinity to their production sites and are highly motivated to safeguard their family's health and produce safe, healthy food. Hence, what is needed is proper education, formalised production conditions through zoning, land use planning and monitoring of food safety.

Land-use planning and zoning based on land use information systems can identify health-hazard-prone areas that need to be more closely examined for their suitability for urban agriculture. Regarding roadsides, potential lead contamination of soil depends on the volume of traffic and the main motor vehicle technologies. Lead is not very mobile in soils, and plant uptake is typically very low, but it is higher in low-growing leafy crops with frequent contact with soil-splash (Brown et al., 2016). Lead stemming from aerosols can be washed off or peeled off in the case of roots (WHO, 2015, 1992). Hedges between roads and production sites also mitigate the traffic-aerosol impact, as do greenhouses. Furthermore, cultivation methods can be adapted for areas with higher metal concentrations, such as by using elevated containers or soil-less cultivation systems (Smit, 2001). Another well-studied possibility is to add organic material to the soil to lower soil acidity and the capability of soils to absorb metals (Attanayake et al., 2015).

One of the overall objectives to be pursued through PGI is the tightening of resource cycles in the urban metabolism. The reuse of solid wastes and wastewater in urban agriculture is an integral component of this objective. Safe management can be achieved by implementing appropriate guidelines for use and treatment standards. Decentralised waste management systems benefit monitoring processes, and pathogens can be reduced through aerobic and anaerobic biological processes. Moreover, the separation of wastewater into black and greywater improves reuse possibilities. Greywater from bath and kitchen sinks requires only simplified processing (e.g., through wetland treatment systems) to be reused. Solid waste can be utilised through composting, which generates heat that destroys pathogens (Smit, 2001).

Adapted cultivation methods can also prevent the spread of diseases through transmitting animals such as mosquitos. The design of sewage, water storage and irrigation systems must avoid long-standing open waters by either keeping streams moving or by covering open water bodies (e.g., through floating plants such as duckweed). Introducing fish that consume mosquito larvae is an alternative (Smit, 2001). Unwanted plant parasites can also be regulated by using microbial insecticides, or insecticides that contain microorganisms such as viruses, bacteria, fungi, protozoa, nematodes or their by-products (Weinzierl et al., 1995). Another important measure is hygiene controls of marketed food produce and labels for 'Good Agricultural Practices' (Smit, 2001).

4.4 Approaches to operationalising PGI

In the past decade, significant progress was made in operationalising and applying green infrastructure planning (see Box 5) as well food system planning (see Box 4). Selected conceptual approaches to PGI and the green infrastructure approach more broadly are laid out here.

4.4.1 Green Infrastructure and Urban Biodiversity for Sustainable Urban Development and the Green Economy (GREEN SURGE)

To underpin its green infrastructure strategy, the European Union funded the research project GREEN SURGE (2013–2017). It was carried out as a collaboration between 24 partners in 11 European countries. State-of-the art planning processes in 20 European cities were analysed, and an in-depth analysis of good practices in 10 cities was performed to develop tools and strategies in Urban Learning Labs. The project defined the four unifying core principles of green-grey integration, connectivity, multifunctionality and social inclusion. A central outcome of the project is a guide for practitioners (Hansen et al., 2017b).

An initial step to start the planning process is to identify locally specific urban challenges to which urban green infrastructure could correspond and to define priorities (1). In this regard, the potential of green infrastructure to adapt to climate change, protect biodiversity, promote a green economy and increase social cohesion is especially important. The plan must then lay out how networks of urban green infrastructure need to be assessed in terms of quantitative and qualitative features and existing supply and demand (2). The guide names a set of potential typologies including allotments, community gardens and agricultural land as a scope for green infrastructure planning and discusses ways to assess their economic, social and ecological dimensions. For example, an Urban Learning Lab in Malmö, Sweden, assessed peri-urban farmland in terms of economic and productive value, social and cultural benefits, biodiversity and regulating functions in close correspondence with the city's Green-Blue Plan for climate change. Based on this assessment, planning authorities shifted from using the entire land area for urban development to maintaining a network of biotopes with a tiered development plan of gradual productivity (p. 49). Subsequently, the guide discusses the development of green infrastructure plans (3). It highlights how urban green infrastructure can be supported by specialised formal or informal green space plans and how important it is to coordinate between different planning frameworks, such as the urban development or climate change adaptation plan.

Another key message of GREEN SURGE is that urban green infrastructure planning needs to be based on the involvement of various stakeholders, ranging from interdisciplinary collaboration between planning authorities to co-creation and co-management of green spaces together with businesses and civil society (4). Regarding implementation, the guide suggests testing new approaches with pilot projects and carrying out monitoring processes to ensure maintenance of urban green infrastructure and identify potential for gradual improvement. Potential financing sources are listed that include institutional funding programmes that oblige investors to create respectively maintain green infrastructure in urban development processes and harness the knowledge and volunteerism of the public (5).

4.4.2 City Region Food System

City Region Food Systems (CRFS) is an evolving conceptual approach and analytical base to improve food system dynamics by operationalising the exchange processes between urban and rural spheres. The approach suggests defining a system boundary of the nearby region and assessing the potential self-reliance within this framework. Tackling sustainability and resource utilisation questions at this scale aligns with the urban metabolism discourse, which identifies urban areas as nodes of densifying flows (see 3.1.1). CRFS are defined as

> the complex network of actors, processes and relationships to do with food production, processing, marketing, and consumption that exist in a given geographical region that includes a more or less concentrated urban center and its surrounding peri-urban and rural hinterland; a regional landscape across which flows of people, goods and ecosystem services are managed. (Jennings et al., 2015).

The approach has gained traction and is promoted by the FAO and RUAF (Blay-Palmer et al., 2018).

Between 2015–2017, a collaborative programme of the FAO, RUAF Foundation and Wilfrid Laurier University developed the CRFS toolkit while assessing and planning sustainable city region food systems in seven case cities: Colombo, Lusaka, Kitwe, Medellin, Quito, Toronto and Utrecht (FAO et al., 2018). The project has shown that the kind of knowledge and approaches that need to be generated are context-specific and depend on local conditions and priorities as well as the extent of already existing data.

The toolkit describes a range of practical steps for defining and mapping the city region, collecting data, and gathering and analysing information of the different CRS components and sustainability based on a multi-stakeholder process engaging policymakers and other stakeholders. The city-specific experiences form a compendium of tools. To get started (1), initial stakeholder meetings, stakeholder mappings, the establishment of a multi-stakeholder taskforce and appointing a focal point and coordinator are suggested steps. In the next phase, boundaries of the CRFS are defined (2), which requires workshops as well as a literature review to be performed. Subsequently, a common vision can be built (3), and the CRFS can be scanned (4), which starts with a workshop to identify local priorities, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and an assessment of existing food policies. On this basis, the design of context-specific data collection is defined for the in-depth CRFS assessment (5). Research questions are tailored for the individual city region. Related indicators define which secondary data source to look for and which primary data survey tool to use (see 4.5.1.2 for a more detailed description of spatial assessment methodologies). This informs policy support and planning (6) and finally governance (7).

4.4.3 Regional Metropolitan Foodscape Planner

The Foodscape Planner is one of a series of decision support tools that allow strategic spatial food system planning on a regional scale, enabling stakeholders to engage in knowledge-driven debate on how to optimise regional food supply. The toolset is a product of the FOODMETRES project (2012–2015) funded by the EU, with case studies in Rotterdam, Berlin, London, Milan, Ljubljana and Nairobi.

The Metropolitan Economic Balance Assessment tool compares food supply and demand by expressing the potential of self-reliance and aggregating staple food groups. In addition to comparing total quantities of supply and demand of the food groups, food security is assessed in terms of nutritional and caloric requirements based on the population's dietary pattern. The Short Food Supply Chain tool characterises regional chains according to their length. The Local Hectares Footprint Assessment tool is a counterpart to assessing global hectares, which are the common unit of footprint analysis. Revealing existing and potential local hectares contributes to people's understanding of the practical opportunities and capabilities of food supply in their region. The tool consists of two complementary tools, the Regional Metropolitan Area Profiles and Scenario, which produces demand scenarios of administrative units as a geo-statistical approach; and the dynamic Regional Metropolitan Foodscape Planner, which enables simulation of different supply scenarios based on land use changes.

The tools utilise existing national and European datasets to reflect consumption in relation to land use and distribution of food groups as well as protected landscape types. The Area Profiles represent a simplified model to determine food balance of regional crops based on land, neglecting goods that need to be imported such as tea, coffee and tropical fruits. The complementary dynamic Foodscape Planner allows a theoretical spatial allocation of food groups for which a supply deficit has been recognised. The allocation is based on a strategic sequential zoning concept: 1) an 'urban core area'; 2) a 'green buffer' reserved for nature and recreation; 3) a 'metropolitan food production zone' differentiated in plant- and protein-based production and 4) a 'transition zone' providing food for the core urban area of zone 1 as well as other close-by settlements. Applying different scenarios with the Foodscape Planner demonstrated that substantial land use changes to balance supply and demand and higher resource efficiency, including a reduction of food waste, and could potentially render most of the case cities self-sufficient in terms of food that can be grown within their biogeographic region (Wascher et al., 2015).

Follow-up research in the cross-national metropolitan region of Antwerp-Rotterdam-Düsseldorf used a simplified approach considering only the transition zone (4) and the 'Metro-Food-Ring', or a combination of the green buffer (2) and metropolitan food production zone (3). This analysis confirmed potential regional self-sufficiency (Wascher and Jeurissen, 2017).

This toolset is likely the most state-of-the-art approach for assessing systemic relations of food connected to spaces at the scale of larger regions. The scope can be adapted depending on existing data and individual geographic and socio-economic conditions.

4.4.4 Continuous Productive Urban Landscapes

One urban design approach at planning urban agriculture is that of Continuous Productive Urban Landscapes (CPULs), developed by architects André Viljoen and Kathrin Bohn. The concept grew from their design research on urban agriculture in the 1990s and manifested in the 'CPUL City concept'. The concept has been discussed in a critical dialogue with invited specialists in two books. The first book, published in 2005, introduced urban agriculture within the urban design discourse. The second book, published in 2014, makes a case for a planned and desired action to establish urban agriculture permanently (Viljoen et al., 2005; Viljoen and Bohn, 2014).

CPUL is a systematic approach and proposal for the 'creation of open urban spaces networks providing a coherent and designed multifunctional productive landscapes that complements and supports the built environment' (Bohn and Viljoen, 2014b, p. 12). CPULs as recreational, outdoor food-growing spaces can be integrated into existing and emerging cities. Food production concentrates on vegetables and fruit because of their high yields and short shelf-life. The productive areas are envisioned as providing and connecting natural habitats and improving the cities' permeability for pedestrians and bicycles. The concept is based on a strong narrative of the productive units. The design of these units is not fixed, emphasising instead the need for context-specific creation.

> In size, they will be as diverse as any other open urban space designs, ranging from 1 to more than 100 hectares. They will be located on inner-urban sites and on city edges, connecting both to continuous landscapes. They will happen on all sorts of open urban space, preferably on brownfield sites to regenerate urban quality. (Viljoen et al., 2005, p. 111)

To address that urban agriculture has not been formalised in European cities, they developed an 'Atlas' comparing different open spaces types with CPULs based on the criteria of 'Spaciousness', or spatial extent and form; 'Occupation', or the value of education, health, communication, etc.; and 'Ecology', or exposure to urban nature. They conclude that the integration of productive elements could potentially enrich the usability of open spaces by offering additional environmental benefits through seasonably changing vegetation, visible ecological cycles and additional activities that might attract a greater variety of occupants (Bohn and Viljoen, 2005). Moreover, the potential of better integrating well-established allotments into the CPUL structure of many European cities is elaborated. Imagined design measures include shared open spaces between productive individual micro spaces that contribute to social cohesion (Crouch and Wiltshire, 2005 as part of the first CPUL book).

After these initial observations in the first book, a series of urban agriculture projects emerged which are examined in the second book. One of the new insights is the relevance of rooftop gardening drawn from many successfully projects in New York (Viljoen and Bohn, 2014).

The approach to developing a CPUL city is to '1) Bring your own city, 2) Map all your existing open spaces and connect them through green infrastructure, 3) Insert agriculturally productive land, 4) Feed your city' (Bohn and Viljoen, 2014c). The approach does not go into detail regarding the methodologies of the mapping and the integration process of productive units.

4.4.5 Summary and conclusion

This subchapter introduced selected conceptual approaches that relate to systemic planning of productive green spaces. These examples do not represent the extent of existing approaches but offer an overview of possible scopes and procedures.

Regarding scope, the selected approaches all deal with green infrastructure and food systems, but no approach considers both spheres equally or explicitly. The GREEN SURGE project analysed state-of-the-art green infrastructure planning in Europe. The resulting guide for practitioners outlines how to set the framework for planning and integrating high-quality, robust green space networks (see 4.4.1). City Region Food Systems represent the state-of-the-art approach for holistic assessment and planning of regional food systems – not least because of RUAF's many years of expertise and the strengthening of the FAO as a global organisation – in which regional food production and hence PGI play a major role. The City Region Food Systems approach focusses on stakeholder interaction, empowerment, and transformation through policy and governance (see 4.4.2). Similarly, the Regional Metropolitan Foodscape Planner derives from the food system discourse and provides informed decision-making and governance using advanced methodologies and software (see 4.4.3). Moreover, CPULs describe potential designs of PGI and can be considered one of the earliest and most known of its kind (see 4.4.4).

The strategic approaches share similarities in their procedures. Initiating a stakeholder dialogue and defining context-specific objectives are the entry point for strategic PGI planning. Bundling existing data across different departments and stakeholders and identifying data gaps follow as the next step. At this juncture, the Regional Metropolitan Foodscape Planner provides an advanced tool to manage and visualise existing regional data and incorporate interregional data sets regarding systemic food relations. Pulling together the data and creating a coherent cross-sectoral analysis is key to agreeing on development goals and identifying appropriate measures.

4.5 Approaches to assessing potential elements of PGI

As the described approaches of operationalising PGI demonstrate, a crucial but difficult step of PGI planning is assessing existing and potential spaces. The prevalence of urban agriculture (see 3.3.2) and its transregional and global extent are far from being coherently documented (Ruel et al., 1998). Regarding the realm of green spaces and potential green infrastructure, cities are more likely to have a certain extent of geographical inventory as there is a longer planning tradition.

This section examines assessment approaches and challenges for green spaces and urban agriculture. As PGI is connected to different thematic fields and disciplines, only selected examples are highlighted to illustrate different dimensions and aspects of assessment methodologies. The review is structured in approaches based on surveys and census data on the transnational and city region scales (4.5.1). The analysis considers approaches that generate an actual geodatabase on the transnational and city region scales (4.5.2). Essential content is synthesised at the end of the chapter, and conclusions are drawn on methodologies of assessing and managing PGI data (4.5.3).

Table 2 Overview of assessment examples related to PGI

Chapter	Author date	Incorporation of existing data sources	Own assessment / analysis methodology	Reference area	Focus topic
Assessment based on surveys and census data					
4.5.1.1	(Zezza and Tasciotti, 2010)	Rural Income Generating Activities (RIGA) database Other multi-purpose household surveys of Worldbank	Comparison of existing documents	Global scale based on analyses of 15 developing countries	Urban agriculture, extent and relation to food security
4.5.1.2	(FAO, RUAF, and WLU 2018)	Various document analyses complementing and guiding own data collection	Individually tailored surveys flanked by interviews, focus group discussion	Colombo, Lusaka, Kitwe, Medellin, Quito, Toronto and Utrecht	Food systems including urban agriculture
Assessment based on land cover and land use geographic data					

4.5.2.1	(Thebo et al., 2014)	Monthly irrigated and rainfed croplands in r 2000 (MICRA 2000) by University of Frankfurt & Global rural urban mapping project (GRUMP) by NASA to identify urban areas	Spatial overlay analysis of existing data through GIS	Entire globe	Urban agriculture, spatial extent
4.5.2.2	(OpenStreetMap, 2020)	Various	Tracing aerial imagery, GPS tracking	Global scale – example Berlin	Land use
4.5.2.3	(Pettorelli et al., 2005)	-	Normalised Difference Vegetation Index (NDV) through GIS	Review of applications	Vegetation productivity
4.5.2.4	(Dige et al., 2014).	CORINE Land cover by EEA Other thematic maps to assess ecosystem services such as the Soil Erosion Risk Assessment model of the European Soil Data Centre	Intersectional analysis of different sources through GIS Connectivity analysis to identify wildlife corridors and potential habitats	European Union, entire land cover	Green infrastructure, spatial and functional extent
4.5.2.5	(Dennis et al., 2018)	Land cover data from multi-spectral imagery from Sentinel 2A satellites Digitalized tree canopy of local NGO OS Mastermap Green space layer, detailed land use data and Lower Super Output Areas census units by UK national mapping agency	Automatic classification of aerial images to detect basic land cover classes Aggregation of land use classes Combination of land cover and land use classes Analyses of resulting datasets according to census units and derivation of 'Landscape Types'	Manchester region, UK	Green infrastructure, spatial extent, social and ecological functioning
4.5.2.6	(WHO 2016)	Urban Atlas by EEA Municipal data on population density	Spatial analysis of proportion of urban population living within a specified distance from public urban green space	European Union, city level	Green space distribution/ access
4.5.2.7	(GALK, 2000)	Guideline for setting up/maintaining green space geodatabase	guideline to commission green space assessment through on-site	Germany, city level	Green space, fine classification for municipal development

			measurement or different methodologies based on remote sensing		and maintenance

4.5.1 Surveys and census data

4.5.1.1 Transnational assessment of urban agriculture by surveys

To date, there have been two studies with a consistent methodology that investigate the global extent of urban agriculture: one based on remote sensing (Thebo et al., 2014) (see 4.5.2.1) and one based on surveys (Zezza and Tasciotti, 2010). The latter was published in 2010 and evaluated 15 developing countries using data ranging from 1998 and 2004. The study was based on nationally representative data from the Rural Income Generating Activities (RIGA) database, which was constructed from a pool of several Living Standards Measurement Studies (LSMS) and other multi-purpose household surveys made available by the World Bank and other national and international institutions. The study adopts has an international perspective by assessing a range of countries from different regions. The resulting data shows the percentage of the population that participates in crop and livestock activities, the total share of income generated from urban agriculture on the country level, the percentage of products sold and the level of food self-supply. The database differentiates between social groups according to their expenditure quintiles, thus deriving a welfare measure that confirms that urban agriculture is more often practiced in poor households. Finally, to assess the relationship between urban agriculture and food security, dietary diversity was assessed based on 13 food groups to compare the amount of food produced and consumed for each item. For some of the case countries, data on kilocalorie consumption was available and put into context with urban agriculture practices, resulting in the finding that urban farmers consume more nutritious diets than non-producing households.

4.5.1.2 City region assessment of urban agriculture

While understanding the global extent of urban agriculture and collecting comparable data is an important research field, individual assessment methodologies within specific regions make sense for deeper understanding and planning on a local level. The research project City Region Food Systems (FAO et al., 2018)(see 4.4.2) has shown that the kind of knowledge that needs to be generated (and therefore assessment methodologies) is context-specific and dependent on local conditions, priorities and the extent of already existing data. For primary data collection in the case cities of Colombo (Sri Lanka), Lusaka and Kitwe (Zambia), the assessment focused on individually tailored surveys accompanied by interviews, focus group discussions and document analysis.

One of Lusaka's identified priorities was sustainable and resilient food production, which led to a series of critical questions such as, ‘Where does the food come from that is consumed in the city region?’. Accordingly, farmers, farming systems and the main production areas of key commodities were assessed. Spatial resolution is expressed as a statistic on the district level instead of as actual geographies. Hence, the extent of individual plots, their distribution in the city and any qualitative features remain unknown.

For Kitwe, one of the priority research questions was also concerned with production and the competition between urban development and agriculture, with related indicators including food volumes from import compared to food originating from the city region. Key informants were interviewed, and questionnaires were administered to 20 farmers. Topics included access to land, trading practices and a wide range of social parameters (e.g., household size and age of members, income). Agricultural production area was assessed via a mix of methods including questionnaires, interviews, mappings of locations and development of land use and land cover maps. The resulting data measures total hectares for individual commodities on the city level (e.g., different types of vegetables such as cabbage, eggplant, etc.). Moreover, ‘food flow maps’ were generated by locating markets and production sites as point data rather than in the form of a polygon of the actual production site.

In Medellin and Toronto, the CRFS assessment focused on assessing existing census data. Food flow maps were generated for Medellin to better understand the status of food flows for each municipality by aggregating imports and exports. Similarly, in Quito, existing data on food consumption and food production in the region was analysed. Data on average household consumption was multiplied with population figures. Production data was drawn from the agricultural census. In the case of Toronto, data availability for all the food systems process components was combined for a more comprehensive understanding and creation of various visualisations.

Surveys, in combination with expert interviews and census data, are necessary to assess socio-economic parameters and systemic relationships between producers and consumers throughout the food value chain. However, by their nature, surveys cannot serve as a spatial assessment of actual geographies.

4.5.2 Assessment based on land cover and land use geographic data

A foundation of any land use planning and management and a prerequisite for strategically planning green space systems including urban agriculture is administering a land information system. In general, cities administer different kinds of land use geodatabases and cadastre that reflect urban development. Remote sensing to update this data is becoming increasingly standard.

Land use information systems

Given that planning processes can keep pace with urban development and prevent excessive informal urbanisation, urban development is guided and monitored on the basis of land cover and land use information systems. However, the prevalence and quality of information systems vary, with the estimation that only 30% of the world's tenure ships are assessed through cadastres in land administration; this holds particularly true for rural areas (McLaren, 2015, 2011).

When land information systems are in place, information relevant to green infrastructure planning is distributed to different divisions, including agriculture, forestry, green spaces and urban planning. Departments of planning and green space planning are of prime relevance due to their strategic approach and holistic perspective.

Remote sensing, land use and land cover classification

A whole scientific branch is concerned with remote sensing and land use and land cover classification (LULC) technologies to create consistent maps.

Remote sensing is usually based on aerial pictures taken by aircraft (airborne) or satellites (spaceborne). Since the early 2000s, the use of Unmanned Aerial Systems through drones has become increasingly significant. Their lower flight height allows them to deliver high-resolution images but makes them inappropriate for quick assessment of larger regions (Stöcker et al., 2019; Xia et al., 2019).

Land use and land cover classification can be derived automatically from image analysis of satellite or aerial pictures. Segmentation of entities can be either pixel-based or object-based. Pixel-based classification is performed at the raster cell level and is most utilised. Object-based classification is an emerging approach to delineating homogeneous objects by merging spatially contiguous pixels into polygons (Petropoulos et al., 2012).

There are numerous automatic classification approaches that can either be supervised or unsupervised. Unsupervised classification is used to partition the image in a number of spectral classes without any classes defined beforehand. Supervised classification is based on predefined classes and training samples in the form of reference data (e.g., existing land use data) or samples collected during fieldwork or from high-resolution aerial photographs (Lu and Weng, 2007).

Land cover refers to the (bio-)physical cover of the Earth's surface, such as vegetation or human-made features. Land use refers to the outcome of human arrangements expressing socio-economic purposes, such as residential areas, social infrastructure, green spaces and so on (Di Gregorio, 2005). It is becoming standard to use existing data to refine automatically classified land cover regarding land use and segregation of parcels. For example, more and more European Countries are applying a 'semi-automatic methodology based on the integration of existing land use data, satellite image processing and generalization' to contribute to the CORINE land cover data of the European Environment Agency (Büttner et al., 2017, p. 4).

On a transnational scale, there is a limited number of land cover datasets that include urban green spaces and urban agriculture (WHO, 2016).

- One example is the CORINE Land Cover (CLC) inventory, which covers large parts of Europe. The resolution is rather low, with mapping units being at least 25 ha and including different types of agricultural areas, forests and semi-natural areas (EEA, 2017a).
- The EEA also publishes the Urban Atlas for selected urban areas with a relatively high-resolution. The minimum mapping unit accounts for 0.25 ha and a minimum mapping width of 10 m. The classification includes 'green urban areas' and different types of agricultural and semi-natural areas (EEA, 2017b).
- A global dataset is that of the Open Street Map project, which provides open-access geodata based on citizen contributions and their local knowledge (OpenStreetMap, 2020) (see also 4.5.2.2).

4.5.2.1 Transnational assessment of urban agriculture by remote sensing

The first approach for a global-scale spatial targeted assessment of urban and peri-urban agriculture was published in 2014 and is based on remote sensing data from the year 2000 (Thebo et al., 2014). The study used a spatial overlay analysis of global-scale land cover datasets. The basis for assessing agricultural production is the 'monthly irrigated and rainfed croplands in the year 2000' (MICRA 2000), originating from the University of Frankfurt. The study identified urban areas with more than 50,000 inhabitants based on the Global rural urban mapping project (GRUMP) dataset by NASA SEDAC and considered productive areas within a buffer of 20 km of each urban area. The data gives an impression on the prevalence of urban agriculture but is now outdated.

Given its global scale, Thebo et al.'s methodology is not suitable for city regions because small-scale agriculture such as 'backyard gardens' were excluded due to limited data resolution (p. 2).

4.5.2.2 Land use assessment based on citizen contributions – OpenStreetMap

OpenStreetMap (OSM) is a global, free and editable map started in 2004 in the United Kingdom. It is 'built by volunteers largely from scratch and released with an open-content license' (OpenStreetMap, 2021a first paragraph). The quality in terms of parcellation and classification structure varies depending on the number of contributions. In some areas, the map is already used by governments and commercial companies. Volunteers are encouraged to 'get out from behind the computer screens', explore their surroundings and collect data with tracking devices, photography and even paper mapping. Map content is than generated by uploading GPS tracks (e.g., of streets), by tracing aerial imagery or by uploading and tracing images of municipal zoning maps (OpenStreetMap, 2021b).

Land use categories are quite differentiated and include different garden types including community gardens.[14] For example, the OSM data for Berlin includes community gardens such as the Prinzessinengarten, which is less than 0.5 ha in size. However, the category 'garden' is not included in the legend of the online map and is only revealed when clicking the single object. Downloading data as shapefiles, which is a common format for further planning processes, requires advanced techniques and is not an option for major export files provided by third parties such as such as Geofabrik.[15] Nonetheless, the information supplied by citizens on urban agriculture is unique as it is not part of the city's opensource map portal (Umweltatlas). Berlin's platform 'Produktives Stadtgrün' includes the locations of over 200 gardens but does not demarcate the actual area of each garden.[16]

4.5.2.3 Methodology for 'greenness', as measured by the Normalised Difference Vegetation Index (NDVI)

While remote sensing can be used for land cover classification by interpretating aerial imagery, it can also be used to estimate the proportion of photosynthetically active wavelengths of light absorbed based on visible and near-infrared light. In this way, remote sensing can detect levels of vegetation productivity. The NDVI ranges between -1 and +1, with values of 0 indicating no vegetation; positive values indicating living vegetation; and negative values indicating water, clouds or snow. The NDVI provides information about spatial distribution in the form of pixel-based images. The assessment gives insight into biomass, CO_2 fluxes and the extent of land degradation in ecosystems (Pettorelli et al., 2005). The NDVI has been used in several studies to investigate the relationship between vegetation and human well-being (WHO, 2016).

The NDVI methodology is useful for assessing the total amount and conditions of vegetation. It does not directly relate to the classification of land cover units, but it can be used as a variable for supervised classification.

4.5.2.4 Methodology for a spatial and functional assessment of green infrastructure in the EU

The report 'Spatial analysis of green infrastructure in Europe' proposes an assessment methodology and conceptual framework aiming to capture the spatial extent and functional extent of green infrastructure regarding ecosystem services (Dige et al., 2014). This twofold approach identifies relevant regulating and maintaining ecosystem services and selects indicators to map capacity. Considered functions include air filtration of vegetation, erosion protection, water flow regulation, coastal protection, pollination,

[14] https://wiki.openstreetmap.org/wiki/Key:garden:type

[15] https://wiki.openstreetmap.org/wiki/Shapefiles

[16] https://www.berlin.de/gemeinschaftsgaertnern/

maintenance of soil structure and quality, water purification, carbon storage and sequestration. Data input is obtained from different thematic maps available on the European level. For instance, the Soil Erosion Risk Assessment model of the European Soil Data Centre was obtained, which uses the parameters of land use, slope, soil properties and climate. The data was intersected with a map of the CORINE Land Cover classes to identify ecosystems dominated by natural vegetation that are situated in high erosion-risk areas.

Moreover, key species or functional groups and their existing and potential core habitats are identified. Connectivity analysis of existing habitats is performed to identify wildlife corridors, and potential habitats are analysed for quality. The identified elements of green infrastructure are classified into conservation networks, comprising areas with key ecological functions for wildlife and well-being, and restoration networks, comprising areas that still provide important ecological functions but with recommended improvements through protection and restoration.

The approach considers and cross-checks a large suite of green infrastructure functions to create new knowledge on highly valuable areas. It is set on a larger scale as CORINE Land Cover units are at least 25 ha.

4.5.2.5 Green infrastructure assessment based on incorporating land use and land-cover

The combination of spatial and functional assessment has also been applied at the city-region level to the case of Manchester, UK. In a recent study, land use and land cover data were used to address physical and functional properties of complex urban landscapes in their social-ecological dimension (Dennis et al., 2018). The study takes advantage of the availability of open-access land cover data from multispectral imagery from Sentinel 2A satellites, with a resolution of 10 m. An automatic classifier was trained to divide the study area into five basic classes: built/impervious, grasses and ground vegetation, forbs and shrubs, tree canopies and water. The data was refined using digited tree canopy data from a local NGO to correct the misclassification of certain shrubs. This basic land-cover classification was then enhanced by incorporating detailed land use data that had also been generated through remote sensing by the UK national mapping agency, titled the OS Mastermap Green space layer. Playgrounds, parks and sport facilities as well as allotments were clustered within the group ‘public parks and recreation’. Other resulting classes include ‘amenity’, ‘private gardens’ and ‘brownfield land’, which were then combined with the land cover classes. Additionally, each class was assigned to the categories ‘urban’ or ‘peri-urban’ derived from existing classifications. All possible combinations led to 35 classes, such as ‘peri-urban private garden tree canopy’ or ‘urban public park grasses and ground vegetation’.

Table 3 Incorporation of land use and land cover data according to the green infrastructure approach (Dennis et al. 2018)

<table>
<tr><th>Aggregated land use classes</th><th>Land cover classes based on semiautomatic classification of Sentinel 2A satellite images</th><th>Class based on boundaries of UK national mapping agency</th><th>Results</th></tr>
<tr><td>Amenity</td><td rowspan="5">Combined with
- Built/impervious
- Grasses and ground vegetation
- Forbs and shrubs
- Tree canopies
- Water</td><td rowspan="5">Combined with
- Urban
- Peri-urban</td><td rowspan="5">35 combined classes</td></tr>
<tr><td>Institutional land</td></tr>
<tr><td>Public parks and recreation</td></tr>
<tr><td>Brownfield</td></tr>
<tr><td>Private Garden</td></tr>
</table>

The resulting dataset was then analysed according to UK-specific spatial census reporting units, or 'Lower Super Output Areas', which are designed to be socially homogenous and reflect tenure, dwelling type, socio-economic status and population density. The 35 landscape classes were used to categorise the Lower Super Output Areas into Landscape Types based on values for percentage cover of each landscape feature and social values of multiple deprivation scores. The Landscape Types were assigned indicative labels based on dominant features and structures such as 'dense greyscape' for highly urbanised types or 'leafy residential' for residential areas with high canopy cover. The methodology is advanced, requiring software such as Arc GIS, QGIS Landscape Ecology plugin LecoS 2.0.7 and the Statistical Package for the Social Sciences (SPSS).

The composite datasets serve as landscape-focussed assessments that influence urban well-being and the connectivity between vegetation types. Classes associated with urban agriculture such as allotments were aggregated but could be in focus as well. Here again, agriculture and forestry are excluded from the assessment but could potentially be integrated.

4.5.2.6 Methodology for quantifying and monitoring green space access

The WHO published a review of evidence on the health effects of green space and health-relevant measures of green space availability, accessibility and usage and has proposed indicators and data analysis tool kits to quantify and monitor green spaces access at the city level (WHO, 2016). The toolkit serves to monitor progress towards the commitment of member states of the WHO European Union to

> provide each child by 2020 with access to healthy and safe environments and settings of daily life in which they can walk and cycle to kindergartens and schools, and green spaces in which to play and undertake physical activity. (WHO, 2010, p. 35)

Three case studies were conducted in Utrecht, Kaunas and Malmö to test various definitions of green spaces and different buffer zones to reach these green spaces. After reviewing available land cover datasets, the study deemed the European Urban Atlas land cover of the EEA to be the most useful. The data is the most up-to-date and has a reasonably high resolution. Population densities are obtained from local municipal sources, and a revised indicator definition and two fully developed methodologies (basic and complex) for estimating indicator value are derived from these. The study provided detailed instruction on carrying out the analysis with Arc GIS software to assess the Urban Green Space Indicator. The indicator defines the proportion of the urban population living within a specified distance from public urban green space. The study bundles state-of-the-art approaches together to improve green space accessibility and glean context-specific target values.

4.5.2.7 German Green Space Information System (GRIS)

Many green space departments administer specific green space geodatabases in Germany, which are also referred to as the green space information system (GRIS). The guideline for establishing a GRIS was developed in 2000 (GALK, 2000). Though the guideline is outdated from a technical point of view, it is nonetheless noteworthy as it combines ecological and social data and provides a solid basis for municipalities to integrate green spaces into urban planning. The GRIS represents disparities in green space supply, ecological peculiarities, necessary renovations and possible solutions. Questions such as

'What is the ratio of shrub, tree and lawn areas?' help assess the maintenance effort needed for optimised green space development.

The guideline suggests establishing an overarching land use layer including morphological types like parks and recreation, playgrounds, or green spaces along roads or allotments, which are further subdivided into classes of vegetation, paved areas, water bodies and others. Vegetation is then further subdivided into different types of lawns, trees, shrubs and flower beds, from which maintenance activities can be derived.

According to a study from 2014 among 41 German cities, green space information systems are the most used instrument to assess qualitative and quantitative constitution of green spaces. They are used by 93% of departments, which also use cadastres specified for trees (85%), compensation areas (78%),[17] on-site inspections (78%) and user surveys (37%; (Böhm et al., 2015, p. 97).

The GRIS offers solid instruction on assessing and managing existing green space systems, but it is outdated as it does not cover current remote sensing techniques. Moreover, it excludes any non-public green spaces, agricultural areas, forests and succession areas since their development and maintenance falls under the responsibility of other departments or citizens.

4.5.3 Summary and conclusion

The analysis of practical examples of assessing green spaces and urban agriculture in this chapter contributes to a better understanding of potential scopes and procedures. As these spaces and practices are part of complex urban systems, a wide range of sources and progressive collection of additional data and information is critical for planning PGI. The following conclusion are made and illustrated (see Figure 14 Dimensions and methodologies of assessing PGI

Assessed geographies of PGI have specific traits and abilities that are interrelated with the broader social-ecological urban metabolism. These parameters impact different flows, such as the yield of productive units or PGI's ability to infiltrate rainwater and buffer urban flooding. For instance, the transnational surveys described here interrogated the relationship between PGI and food security (see 4.5.1.1). The City Region Food System Assessment dived deeper into the regional context by examining distinctive features and social-ecological relations (see 4.5.1.2). Moreover, advanced spatial analysis reveals relations between social indicators and the spatial distribution of green spaces. For example, the WHO tool to identify Urban Green Space Indicators analyses the accessibility and availability of green spaces for the urban population (see 4.5.2.6). These interrogations demonstrate that besides a geospatial assessment, surveys and expert interviews are also needed to understand the driving forces of the current state of PGI and to start a stakeholder dialogue for further planning steps and a common vision.

The approaches based on surveys (4.5.1) provide crucial quantitative and qualitative information of the social-ecological dimension, such as average engagement in urban agriculture in relation to income and other social indices. However, surveys do not generate a geodatabase with the actual demarcation of spaces. Surveys may be captured in the form of points with a geodatabase, but they do not outline plots.

PGI refers to a spatial structure consisting of different kinds of productive green spaces as part of a larger green infrastructure network. Creating an adequate planning base requires assessing existing and potential spaces and information about their condition through a comprehensive geodatabase.

Classifications of land cover (vegetation with potential sub-classes, water bodies, built/impervious) and land use (e.g., parks, amenities, institutional land) are determined based on local, context-specific conditions. Advanced approaches integrating both types of geographic data have been developed to better assess interrelated social-ecological conditions of the spaces (see 4.5.2.5) and other functional aspects by incorporating thematic maps (4.5.2.4).

City departments administer different kinds of land information systems with geodatabases related to green spaces, urban planning, urban infrastructure or nature reserves and compensation. They often also comprise thematic analytic maps of, for example, urban heat islands or urban flooding, which can be crucial to determining the goal of systemic green spaces planning (4.4.1). Green space geodatabases are ideally established regardless of ownership, including private gardens and green spaces within the areas of industry and commerce, as these can still be subject to planning through legislative guidelines for protection and maintenance (see conception of green infrastructure 3.5.1).

[17] According to German regulations, interventions into nature through construction or other means must be compensated by upgrading or creating other natural elements

There is a recursive relationship between grown information systems and new forms of land cover assessment through remote sensing. It is becoming more standard to use existing data to refine automatically classified land cover. The open mapping platform OpenStreetMap shows how local knowledge can be harnessed. One of the preferred ways to add information is tracing aerial imagery, which provides high-resolution and specific data (4.5.2.2).

Generally, assessing green infrastructure and PGI can be achieved through on-site measurements, or the most precise method applicable for single objects that is often carried out after incorporating newly constructed sites, and remote sensing and land cover/land use classification, which allows the assessment of a complete land cover dataset. Collecting field references as well as manual aerial picture interpretation and tracing highly improves supervised classification.

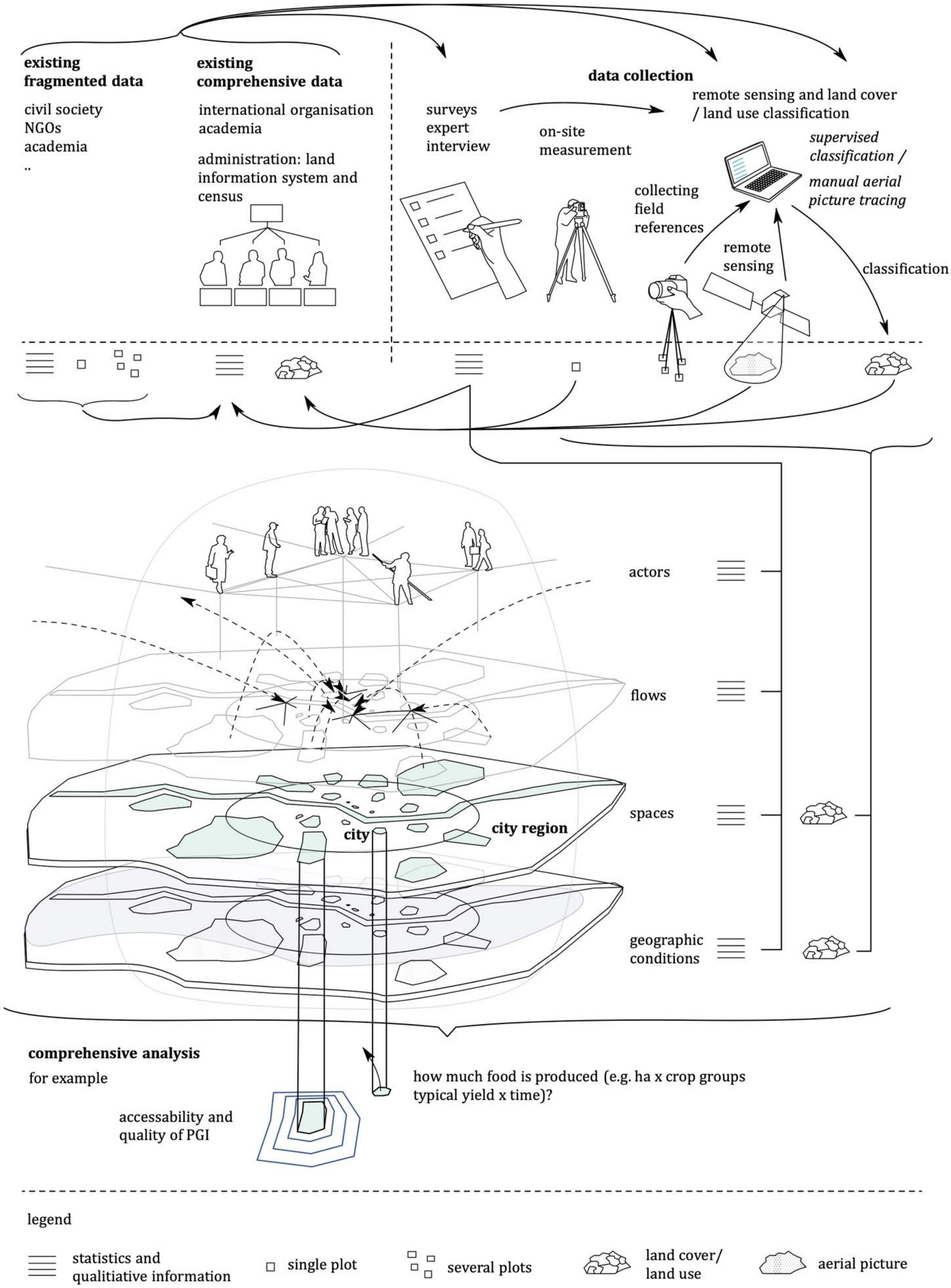


Figure 14 Dimensions and methodologies of assessing PGI

4.6 Challenges of PGI planning

Despite growing recognition of their importance, both the planning of urban food systems and green infrastructure are far from being carried out successfully and comprehensively in most cities. It seems that more cities in the Global North engage in these practices compared to the Global South (see Box 4). However, rapidly urbanising regions in the Global South could benefit from proactive food system and green infrastructure planning to avoid or mitigate escalating urban challenges, such as increasing socio-environmental inequalities, food insecurity, environmental depletion, vulnerability of supply networks.

4.6.1 Decoupled spheres

Human-induced planetary alterations and their negative consequences are not tangible enough to trigger adequate countermeasures (Latour, 2018; Morton, 2011). The complexity of *'planetary urbanisation'* (Brenner and Schmid, 2014) makes it difficult to demarcate system boundaries, analyse metabolic interrelations and therefore plan territory.

> We inhabit systems of systems, where multiple levels of complexity exist, co-exist, converge, and collide. Those systems are always incomplete and imperfect, influenced and induced, never completely open nor completely closed. They are always mediated by one form of infrastructure or another, usually under the influence of various states and scales of control. (Bélanger, 2017, p. 13)

As systems become increasingly complex, the responsibilities and division of labour, the connected spheres of urban and rural, the health of ecosystems and human beings, the adherent urban metabolism of nutrient and water extraction and return, and production and consumption are becoming more decoupled. This distorted and elevated urban metabolism and the multiplication and diversification of interconnected infrastructures, flows, processes, actors, and spaces pose difficulties to comprehensive analysis and planning (Pothukuchi and Kaufman, 1999; Wiskerke, 2015).

Despite global interconnectedness and effects such as tele-coupling (2.1.2), contemporary discourses of urban metabolism also underline the important relationship between urban systems and their immediate region in terms of nutrient and water cycles, supplying resources and receiving wastes (Zhang et al., 2015, pp. 11253–11254). Similarly, the City Region Food Systems approach argues for a regional scope (4.4.2). Green infrastructure is a spatial approach at the regional scale. It focusses on a continuum of green to grey infrastructures that are enhanced to improve metabolic exchange processes between natural and urban systems (see Box 5).

4.6.2 Limitations to PGI planning due to the allocation of responsibilities

In practice, one of the main obstacles to PGI planning lies in the dichotomy between urban and rural policy, with any type of agricultural provisioning belonging to the rural sphere located 'outside' the city (Giseke et al., 2015b; Wiskerke, 2015).

In the reality of planning, what can be understood as PGI in the local context is spread across different responsibilities.

- Administratively, agriculture, green spaces, and urban planning are most likely dealt with by different governmental bodies (Giseke et al., 2015b; Wiskerke, 2015).
- Spatially, planning authorities and planning data are bound to administrative territories and require intercommunal and interregional cooperation. Urban food systems need to be analysed on large scales, often exceeding the administrative boundaries of cities (Jennings et al., 2015)(see 3.2 and 4.4.2)
- Regarding the public/private dimension, large parts of urban food systems are managed by the private sector, thus evading strategic planning processes (Vitiello and Brinkley, 2014) (see Box 4).

Overarching challenges in the Anthropocene can only be addressed in an integrative manner, requiring transdisciplinary cooperation and the courage to explore new possible futures.

4.6.3 Lack of data and challenging assessment of urban agriculture and green infrastructure

The assessment of both urban agriculture or green infrastructure and their complex social-ecological functioning remains challenging for several reasons.

Urban agriculture is often characterised as spatially dispersed, consisting of elements that vary drastically in size (Lovell, 2010). To date, urban agriculture projects are often carried out on an individual scale, while a city-wide inventory and 'big-picture' visions are missing (Zeunert, 2018). A lack of agreed-upon definitions for urban agriculture has hindered data collection (Ruel et al., 1998). Additionally, food production and food retail are part of the informal sector, particularly in developing countries (FAO, 2003). Thus, while some cities have an inventory of green spaces, urban agriculture is often carried out by individuals as an informal practice that is not recognised as a valid type of green space. Moreover, the role of small-scale urban agriculture in contributing to food security is rarely quantified with spatial reference as this analysis evades the thematic fields and adherent administration of agriculture, trade, green space, and urban planning as well as health and nutrition. Generally, the census calculates output per crop of rather large-scale entrepreneur agriculture, with small-scale urban patches often being omitted from the statistics. Small-scale urban agriculture practiced by individual households may be assessed using questionnaires that generate crucial information but that offer limited reference to geospatial data (see 4.5). Hence, existing urban agriculture is poorly inventoried and not well equipped to resist urbanisation.

The lack of spatial accuracy and information about the functioning of PGI is also reflected in the allocation of space through urban planning processes. A lack of assessment of potential and existing spaces means that there is no concrete planning basis for the implementation and development of PGI, which weakens its position in negotiating for land – one of the most valuable resources in growing urban areas. The WHO recently published a guideline for quantifying and monitoring access to green spaces in cities (WHO, 2016) (see also 4.5.2.6), but there is no international minimum standard for urban green space because social-ecological systems differ too much. Green space standards may be negotiated and anchored individually under difficult conditions or not at all.

4.7 Summary and conclusion

The chapter laid out this dissertation's understanding of PGI, which is seen as a further conceptualisation of the green infrastructure approach (4.1). PGI is understood as elements of urban agriculture that are assessed and operationalised as part of a strategically planned green infrastructure network. More specifically, in the context of rapidly growing regions in the Global South, this dissertation anticipates that *green infrastructure can serve as a strategic planning approach to operationalise existing social movements of urban agriculture*, which are not well equipped to resist urbanisation.

Green infrastructure connects the health of ecosystems and humans by ensuring liveability for citizens, increasing biodiversity by developing and connecting habitats, and mitigating the effects of climate change (Hansen et al., 2018; Tzoulas et al., 2007). It is a spatial planning approach focussing on creating a network of green spaces and improving their quality and functioning in the city. The conceptual PGI approach emphasises provisioning functions and tackling questions of resource utilisation in the urban metabolism. In this sense, PGI incorporates the combined benefits of developing and maintaining a green infrastructure network and increasing the share of regionally produced food as part of urban food system planning (4.2). Poor applications of PGI can also lead to specific disadvantages, which can be avoided by taking appropriate measures (4.3).

There are related approaches that deal with green infrastructure and food systems, while no approach has been found that considers both spheres equally or entirely explicitly. They all transcend disciplines and aim at a comprehensive assessment of spatial structures, relevant driving forces, stakeholders and their power relations. They pursue integrated and participatory planning processes, which are the basis for building a cross-sectoral common vision and identifying appropriate goals and measures. Green spaces, including urban agriculture, are shaped by practices, power relations, norms and the geographic conditions of biotic and abiotic factors. To understand possibilities as well as challenges for preserving existing structures and integrating PGI into urban planning processes, individual questions and priorities need to be defined and explored (4.4).

For participatory and integrated planning, applying local knowledge and creating a common vision are essential. Comprehensively assessing *spaces* of both urban agriculture and green infrastructure and their complex social-ecological functioning is a crucial but difficult step. Upon analysing different spatial assessment approaches, an overview of possible methodologies and dimensions was generated. Assessing the spatial manifestation of PGI is crucial to generating a planning base and identifying qualities and options for integrating PGI into ongoing urban development processes. *A comprehensive geodatabase can be generated by remote sensing classification of land cover/land use, but this needs refinement through field trips and aerial image interpretation and tracing* (4.5).

At the same time, the complexity of these systemic relations challenges comprehensive assessment and planning. Related aspects are often spread across various authorities. More research is needed to identify adequate methodologies for spatially and functionally assessing the dispersed green space and urban agriculture structures that could become part of a PGI network (4.6).

PART III CASE STUDY OF DA NANG, VIETNAM

5 METHODOLOGY OF EXEMPLIFYING THE PGI APPROACH IN THIS DISSERTATION

To exemplify the PGI approach through the case of Da Nang, Vietnam – a rapidly growing city with a high prevalence of urban agriculture – a series of parallel and recursive working steps are carried out, which are documented in five blocks. This dissertation has its background in landscape architecture and pursues an abductive approach with 'selective sampling and rapid reconnaissance from different fields, often borrowing broad-based knowledge' (Bélanger 2017, 10–11), including geography, cartography, environmental sciences and urban planning.

The author's research assistance in the project 'Rapid Planning, sustainable Infrastructure, environmental and resource management for highly dynamic metropolises' (2014-2019), enabled several research trips to Da Nang, taking part in joint research with local stakeholders and conducting a series of field trips and mappings. The 'Rapid Planning' project focused on detecting and deciphering the urban metabolism of fast-growing cities and developing a rapid 'trans-sectoral' urban planning methodology in three case cities – besides Da Nang, Kigali, capitol of Rwanda and the city Assiut in Egypt. Results from the project are document in a final report (see (Kasper et al., 2019).

Comprehensive overview of Da Nang (Chapter 6)

First, Da Nang's social-ecological system, driving forces and interrelationships within the wider context of planetary alterations is explored. Da Nang's relevance in contributing to these alterations as well as their consequences for Da Nang are outlined. The analysis is based on a literature review and on-site experiences through different field trips and collaboration with local stakeholders.

Analysis of Da Nang's urban planning frame with relevance to PGI (Chapter 7)

The planning framework of existing planning policies as well as visions and goals for future urban development and green space planning are reviewed in relation to PGI. The driving forces that lead to a loss of agricultural areas as well as measures to maintain and develop urban agriculture are assessed. The analysis is carried out through study of policies and scientific literature and observations from field trips. Moreover, the values and opinions of local experts and authorities gathered during the research phase are analysed.

Assessment of spatial and systemic dimensions of urban agriculture (Chapter 8)

Assessment of urban agriculture begins with an overview of urban agriculture knowledge based on existing plans, statistics and data gaps. The review underlined the need for more detailed approaches to assess urban agriculture's spatial manifestation and its connectedness to the urban metabolism.

Accordingly, a new approach was developed to assess and characterise urban agriculture through spatial typologies. A workflow of mappings was created to identify features and typologies of urban agriculture by collecting references for aerial picture interpretation and geodata collection and processing.

The assessment mounts in a consolidated overview of urban agriculture's role in the city's urban food system and answers the question of how much these spaces contribute to food supply in the region.

Envisioning future developments of urban agriculture in the context of the urban metabolism (Chapter 9)

The relationship between urban agriculture typologies and urban metabolism is further conceptualised by defining main components and processes as mathematical equations that are then substantiated with coherent datasets. The resulting simulation blocks are integrated into the simulation model developed in the 'Rapid Planning' project, making it possible to simulate different urban metabolism scenarios for future urban agriculture development as part of an integrated infrastructure system.

Researching and estimating the parameters and relationships was done based on literature reviews and expert consultation in the scenario-building workshop of the 'Rapid Planning' project.

Envisioning a green infrastructure system with PGI (Chapter 10)

A PGI draft vision was developed as part of a city-region-wide green infrastructure plan. Using the tools of landscape architecture, a spatial framework for city-region-wide green infrastructure and its potential contribution to local goals in urban planning are drafted. Model-like assumptions from the scenario simulation are further elicited by exemplarily developing spatial design solutions for two sites. Reflections on potential links to existing planning frameworks and procedures are based on policies and scientific literature.

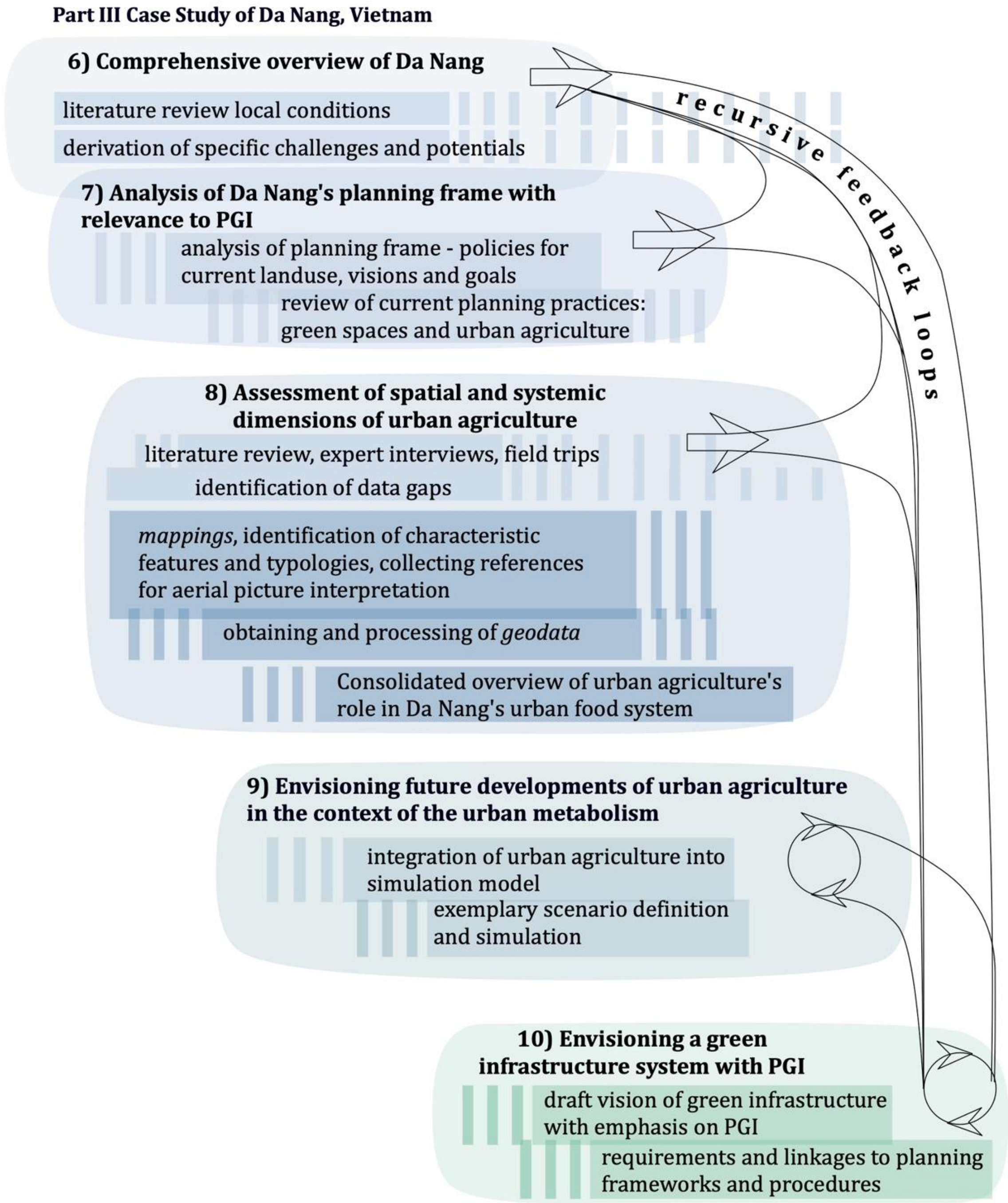


Figure 15 Overview of methodological steps to assess urban agriculture and envision PGI

6 COMPREHENSIVE OVERVIEW OF DA NANG

This chapter introduces Da Nang, its urban development (6.1) and the ecological system's basic conditions and dynamics regarding the interrelated dimensions of its topography, hydrology, climatic conditions and occurring flora and fauna (6.2). The relationship between the local city region of Da Nang and human-induced planetary alterations is briefly described. Connecting back to global-scale challenges (Chapter 2.5), the local manifestation of rapid changes in land cover and consumption of resources are laid out alongside local negative implications (6.3).

6.1 Da Nang's urban system

6.1.1 Introduction

Da Nang is Vietnam's fifth largest city, with about one million inhabitants in 2016 (Da Nang statistics office, 2016). Da Nang lies at the intersection of major road, rail and sea routes. The city is in the middle of the country and represents the main sea gateway of the Central Highlands.

The administrative boundaries of Da Nang comprise a large territory of about 128,000 ha, with about 99,000 ha of terrestrial space and 30,000 ha of territorial waters and the archipelago Paracel Island. Hence, administratively, Da Nang can be considered a city region (DOC, Da Nang, 2015, p. 6).

Figure 16 Location of case study Da Nang, based on GADM

6.1.2 Urban development in Vietnam

Rapid demographic and social changes are happening in Vietnam. The population grew from 32 million in 1960 to 96 million by 2019 (World Bank, 2020). Growth is expected to slow down as the fertility rate has decreased significantly, dropping from about 6.5 children per woman in 1969 to two children in 2000, where it has remained (World Bank, 2018).

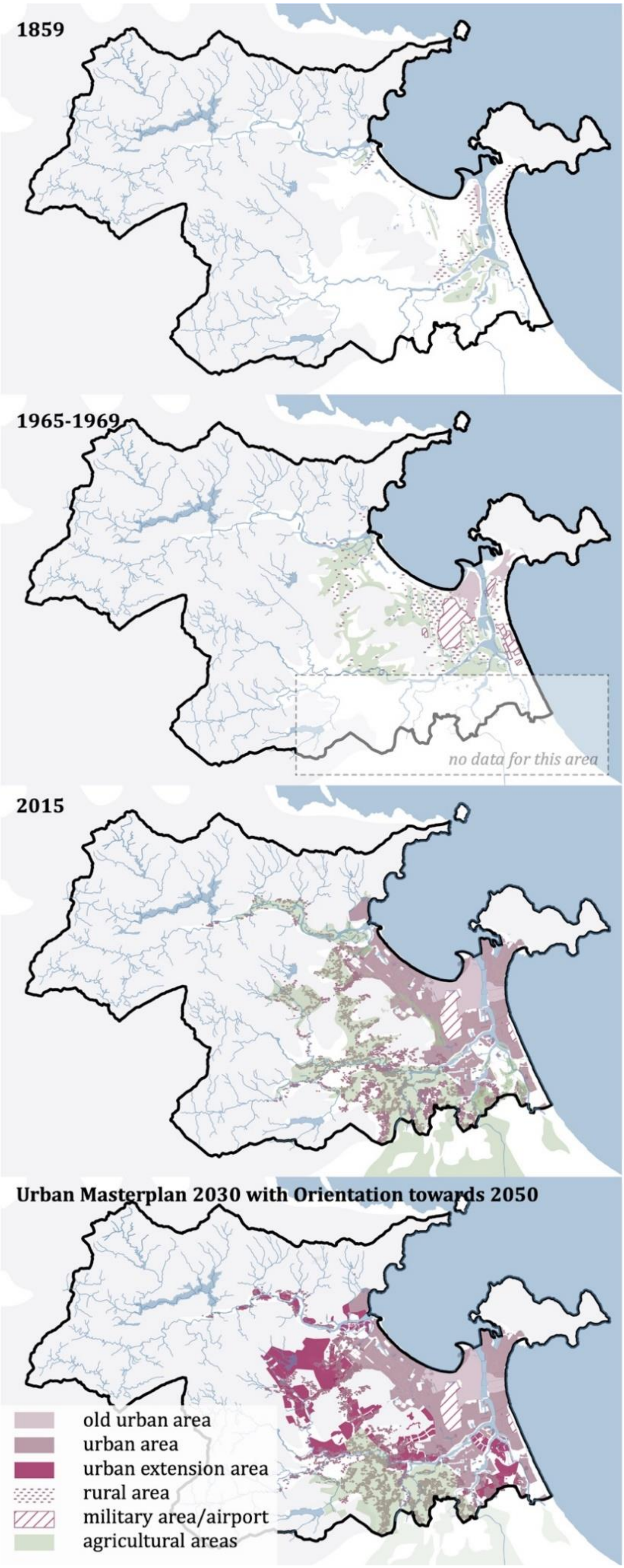
With the *Doi Moi* reform in 1986, Vietnam made extensive efforts to transition from a centrally planned economy to a market-based economy with a socialist orientation (Fan et al., 2019; Socialist Republic of Viet Nam, 2011). This development resulted in a dramatic shift from an agriculture-based economy towards service and industry. The reform was also a response to widespread malnutrition and severe food shortages. In 1988, collective farming was abolished, and individual households were recognised as autonomous units (see more on Land Law 7.1.1). Further strengthening of land use rights and privatisation of production in 1993 led to rapid improvements, and Vietnam become one of the largest rice exporters by 1997 (Le, 2020, p. 4). Economic liberation and ongoing growth transformed Vietnam from one of the poorest nations into a lower-middle-income country (World Bank, 2020).

6.1.3 Urban development of Da Nang

Analysis of historic maps indicates that Da Nang was sparsely populated until the 19th century. Settlements and agricultural areas grew along with the population, which led to progressive deforestation of Da Nang's delta. During the Vietnam War, the city was a major base of the U.S. military, particularly the U.S. Marines, which led to multiple and intense alterations to the city's social-ecological system. Among other infrastructures, two airports were built in 1964, the larger of which remains in operation today as a domestic airport (Tregaskis, 1975).

With its strategic location at the intersection of several infrastructure networks (DOC, Da Nang, 2015), Da Nang has one of the highest urbanisation rates in Southeast Asia (Fan et al., 2019). The greater Vu Gia Thu Bon river basin region currently hosts approximately 2.5 million people, of which 80% live in the coastal lowlands and 45% in urban areas. The whole area reports high migration rates toward Da Nang (Trinh et al., 2017). Urban development is concentrated in the lowlands, 'where dense population, high concentration of industry, services and intensive agricultural activities support dynamic growth', whereas the midlands are characterised by forestry and agriculture (Trinh et al., 2017).

Within the administrative area of Da Nang, the population is estimated to increase from 890,292 in 2014 to about 2.3 million by 2030. In response to this, the city has designated large areas for construction in the current Masterplan (DOC, Da Nang, 2015). Organising urban growth is challenging because only 22% of the territory is considered suitable for urban development due to the topography (JICA, 2010a, pp. 5–4). Large portions are mountainous, and the delta area of the Han River is prone to flooding. As suitable space is limited, urban extension will need to make increasing use of agricultural areas.



Initial villages of Da Nang grew at the estuary of the Han river, with many residents living from fishery

(map sources: Map of Tourane (Da Nang) found in the home of a mandarin of the Vietnamese military in 1859; Map of Touran 1859 displayed in Museum of Da Nang, interpreted by Daniel Bodenstein (2018))

During the Vietnam War, large areas of the city were used for military purposes

(map sources: U.S. army corps of engineers, army map service, compiled in 1968, scale 1:50,000; U.S. army Engineer Battalion compiled in 1969, scale 1:25,000)

Rapid urbanisation and relocation of agricultural landuse

(map sources: land use plan data Hue University 2015; aerial picture interpretation of RapidEye scene 2015)

Planned urban expansion due to anticipated ongoing population growth, reduction of agricultural landuse

(map sources: Urban Masterplan 2030 with Orientation towards 2050, issued 2013)

Figure 17 Past and future of Da Nang's urban development, map 1859 based on (Bodenstein, 2018)

6.2 Da Nang's ecological system

6.2.1 Topography

A key feature of Da Nang is its diverse topography comprising high mountains (highlands), medium-elevated terrain (midlands) and low-lying plains towards the coast (lowlands). The lowlands are part of the large Vu Gia Thu Bon river basin, named after the Vu Gia and Thun Bon Rivers. The northern edge of the basin is bordered by the Bach Ma mountain range. The steep Truong Son Range (also called the Annamite range) runs parallel to the Vietnamese coastline for more than 1,100 km and forms the western edge of the basin. Mountainous terrain covers a large area of Da Nang, with peaks between 700 and 1,500 m and many slopes steeper than 40%, which are mostly covered by forests (DOC, Da Nang, 2015, p. 7). These mountains account for about three fourths of the city (JICA, 2010b, pp. A5-8). Large parts of the low-lying plains serve as paddy fields and for other agricultural uses, but these increasingly compete with urbanisation (see 7.3.2).

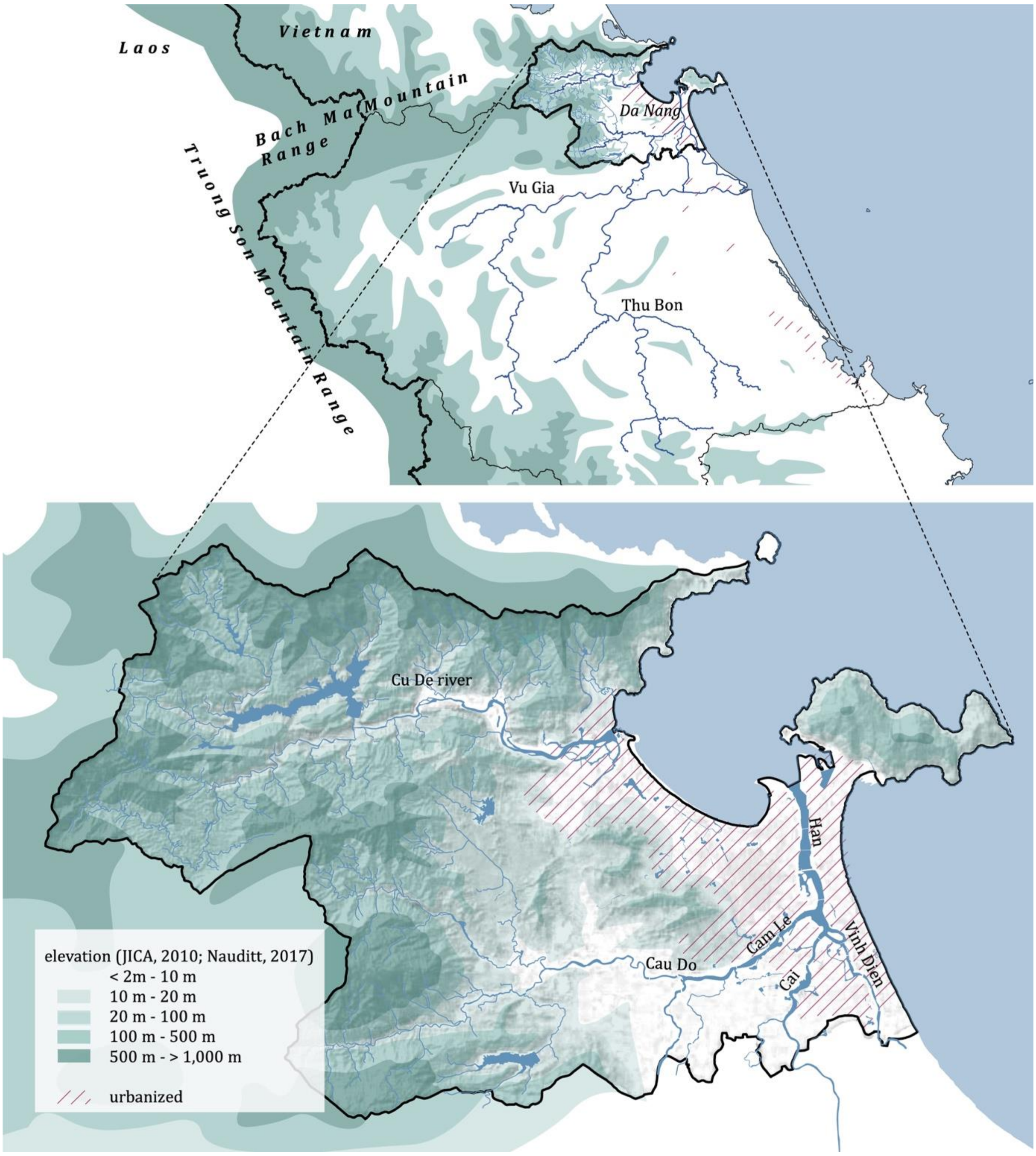


Figure 18 Topography of Da Nang and the greater region of the Vu Gia Thung river basin

6.2.2 Hydrology

Da Nang lies at one of the two main estuaries of the Vu Gia Thu Bon river basin. The Vu Gia and Thu Bon Rivers originate in the Truong Son Mountains and form Vietnam's ninth largest river basin (Trinh et al., 2017). The rivers occupy largely separate basins that are connected downstream through the Vinh Dien and the Que Hang Rivers about 30 km from the coast before they flow into the sea. The city of Hoi An, with approximately 150,000 inhabitants, lies at the neighbouring interconnected estuary of the two water bodies. The river systems are also connected upstream through the Dak Mi hydropower project and an inter-basin transfer pipe and canal (Buurman et al., 2015). Together, both basins form a *'braided river delta system'* which interacts more intensely during the wet season. During the dry season, the interconnection is sometimes interrupted (Trinh et al., 2017). The topographic and hydromorphological conditions are favourable for agriculture as the mountainous areas provide numerous water reservoirs that irrigate the basin (Buurman et al., 2015), while the coastal plains are fertile due to sediment.

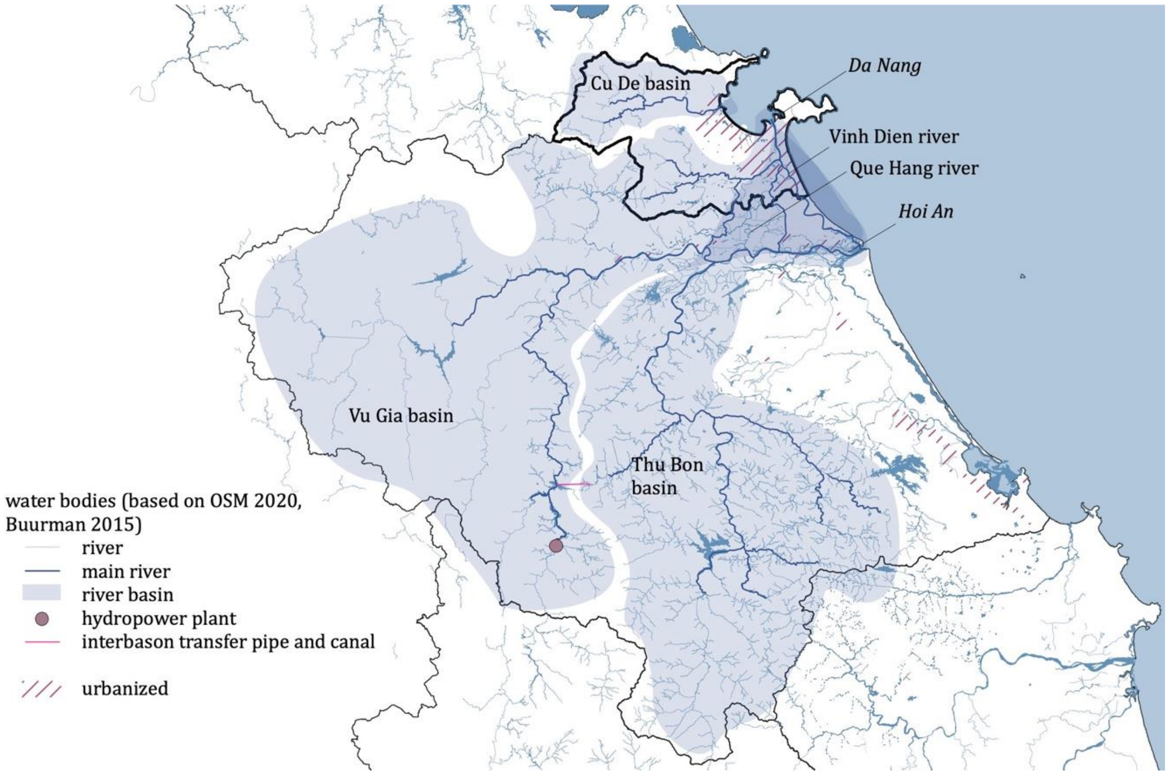


Figure 19 Water bodies and river system in the region of Da Nang

6.2.3 Climate

Da Nang's climate is characterised by pronounced dry and wet seasons which last six months each. The Bach Ma hill range and the Truong Son mountain range frame the coastal plains of Da Nang and the entire Vu Gia Thu Bon basin, resulting in relatively warm winters and dry summers. The dry season lasts from January to August, with particular dryness from February to April, which can cause harsh droughts (Trinh et al., 2017). Subsequent low river levels lead to saline intrusion from the upstream inflow of seawater, affecting water supply sources for citizens (DOC, Da Nang, 2015, p. 8). In severe cases, citizens can no longer use tap water and are dependent on bottled water or tanker trucks. Saline intrusion also affects agricultural production as irrigation water is pumped from the rivers. In 2012 and 2013, it was necessary to pump water from an upstream reservoir to supply Da Nang's fields, causing additional costs of more than 600,000 USD in 2013 alone (Buurman et al., 2015).

Da Nang's geographic position leads to high exposure to north-eastern monsoons, which can cause heavy and long-lasting rains. A total of 40%–50% of the annual rainfall happens in October and November, rendering the coastal plains of Da Nang prone to urban flooding. On average, it rains 144 days of the year, with an average rainfall of 2,066 mm (DOC, Da Nang, 2015, p. 8). From September to December, the area is often affected by typhoons (Trinh et al., 2017). The average annual temperature is 25 °C, with 40 °C being the highest and 10 °C the lowest temperatures.

6.2.3.1 Flora

Vietnam is one of the few countries with increasing forest coverage following severe damage during the Vietnam War from 1965 and 1975. Coverage grew from 25%–31% in 1991–1993 to 32%–38% in 2005, with equal gains from natural forest regeneration and plantations (Meyfroidt and Lambin, 2008). The Annamite mountain range, which encloses the Da Nang region, has been identified as an area of global conservation priority of critical biological importance. The area is part of the Global 200, constituting a worldwide representative ecoregion of tropical moist broadleaf forest (Olson and Dinerstein, 2002) (see also 2.2.2.1).

The foothills of Da Nang are covered by forests, which constitute 65% of the terrestrial territory and are considered the 'lungs of the city' by local authorities (CCCO Da Nang, 2014a) and of 'high value to the city as they balance the ecosystem, maintain biodiversity and supply materials' (CCCO Da Nang, 2014b). The Department of Agricultural and Rural Development (DARD) categorises five types of forest: rich/dense forest, average forest, poor/sparse forest, restored forest, and artificial forest (see Figure 20; (JICA, 2010b, pp. A5-104). Tree species richness increases closer to the Annamite mountain range. The forests of Central Vietnam are mainly characterised as broadleaf evergreen forests with tropical tree species. In more elevated areas, temperate forests with Lithocarpus or Nageia tree families prevail (Raedig et al., 2017). Current efforts aim at further afforesting these indigenous species in Da Nang (CCCO Da Nang, 2014b).

However, in the Da Nang region, large parts of the forests consist of plantations dominated by non-native, mostly fast-growing Acacia, Eucalyptus and Pinus species (CCCO Da Nang, 2014b). In Da Nang's territory, this is the case for areas classified as artificial forests or productive forests. Most of the lowlands have already been deforested and converted into agricultural or urban land. Moreover, forests in the region of Da Nang face fragmentation due to the expansion of agricultural activities and adherent road networks, leading to habitat shrinkage, larger dispersal distances and biodiversity loss (Raedig et al., 2017).

6.2.3.2 Fauna

Vietnam is considered rich in biodiversity, with many different ecosystems and species due to the diverse terrain, soil, and climatic and hydrological conditions. Typical ecosystems include forests, mangroves, coral reefs and seagrass ecosystems (MONRE, 2019). The Annamite mountain range is home to a wealth of wildlife. Research on wildlife has been sparse but is increasing, with primates being the focus of conservation efforts. The Ba Na-Nui Chua Nature Reserve in Da Nang is inhabited by a range of primates, including yellow-cheeked gibbons, red-shanked douc langurs, stump-tailed macaque, pig-tailed macaque, pygmy loris (Tuan et al., 2019), rhesus macaque and flying lemur (CCCO Da Nang, 2014b). Some of these primates, such as the red-shanked douc (Tran Van et al., 2019), also live in the Son Tra Peninsula and are considered rare endemic primates in Vietnam (CCCO Da Nang, 2014b). Other species include pangolin, pheasants, crested argus, bears, Asian golden cats, wildcats and slender loris. The Ba Na-Nui Chua Reserve hosts at least 44 endangered species, while the Son Tra Reserve hosts 15 (CCCO Da Nang, 2014b).

There are few long-term observations on species occurrence, so it is not possible to determine whether biodiversity is declining or increasing. However, it is assumed that intensifying tourism and agriculture impacts biodiversity (Raedig et al., 2017; Tran Van et al., 2019). No information could be obtained on the occurrence of wildlife in agriculture-dominated lowlands or urban areas.

6.2.3.3 Protected areas

In Da Nang's land use plan, classification of forest conditions is reflected in the zoning of areas for *special* use, which comprises touristic and recreational uses of mostly dense forests on steep topography, protection of some sparse and restored areas and productive use of artificial forests. These categories (special use, protection and production) are found in the Urban Masterplan 2030, in land use plans and in the statistical yearbook. Some of the areas classified as special use belong to a national network of protected areas. The Ba Na-Nui Chua and the Ban Dao Son Tra Reserves are part of a decree by the Vietnamese Ministry of Agriculture and Rural Development (Decree 2370/QĐ/BNN-KL, issued 5th of August 2008). The establishment of the Ba Na-Nui Reserve dates back to 1986 and was expanded in 2013 (Tuan et al., 2019). The Son Tra Peninsula has been reserved since 1977, but its size has been reduced from circa 4,000 to about 3,400 ha in favour of national tourism development and the establishment of resorts (Tran Van et al., 2019).

Maintaining biodiversity is one of the key objectives of the Action Plan to Proactively Respond to Climate Change and Enhance Resource Management and Environmental Protection of Da Nang City issued by the City People's Committee on 4 March 2014 (Decision 1349/QD-UBND).

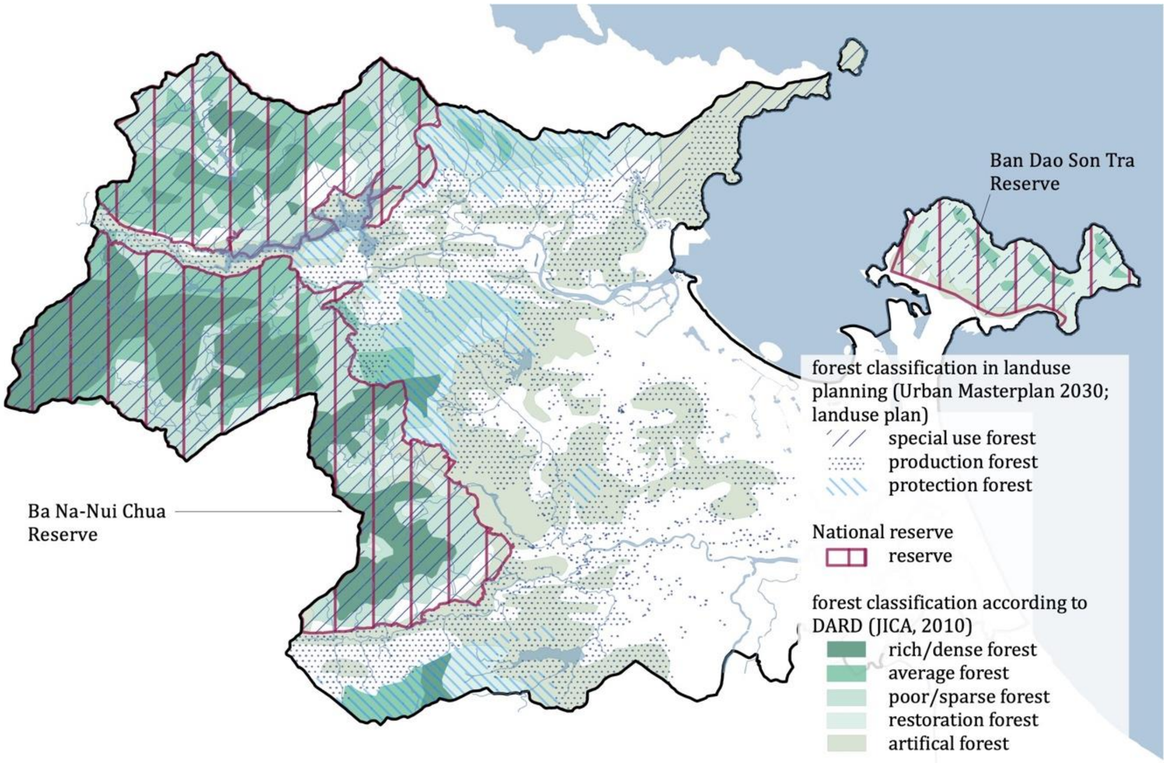


Figure 20 Forests classification and protected areas of Da Nang

6.3 Conclusion: Contribution to and impact of human-induced planetary alterations

The city region of Da Nang is a magnifying glass for human-induced planetary alterations as both a contributor to these changes and a site of their effects. The following sub-sections give a brief overview of local conditions, driving forces and the impact of planetary alterations.

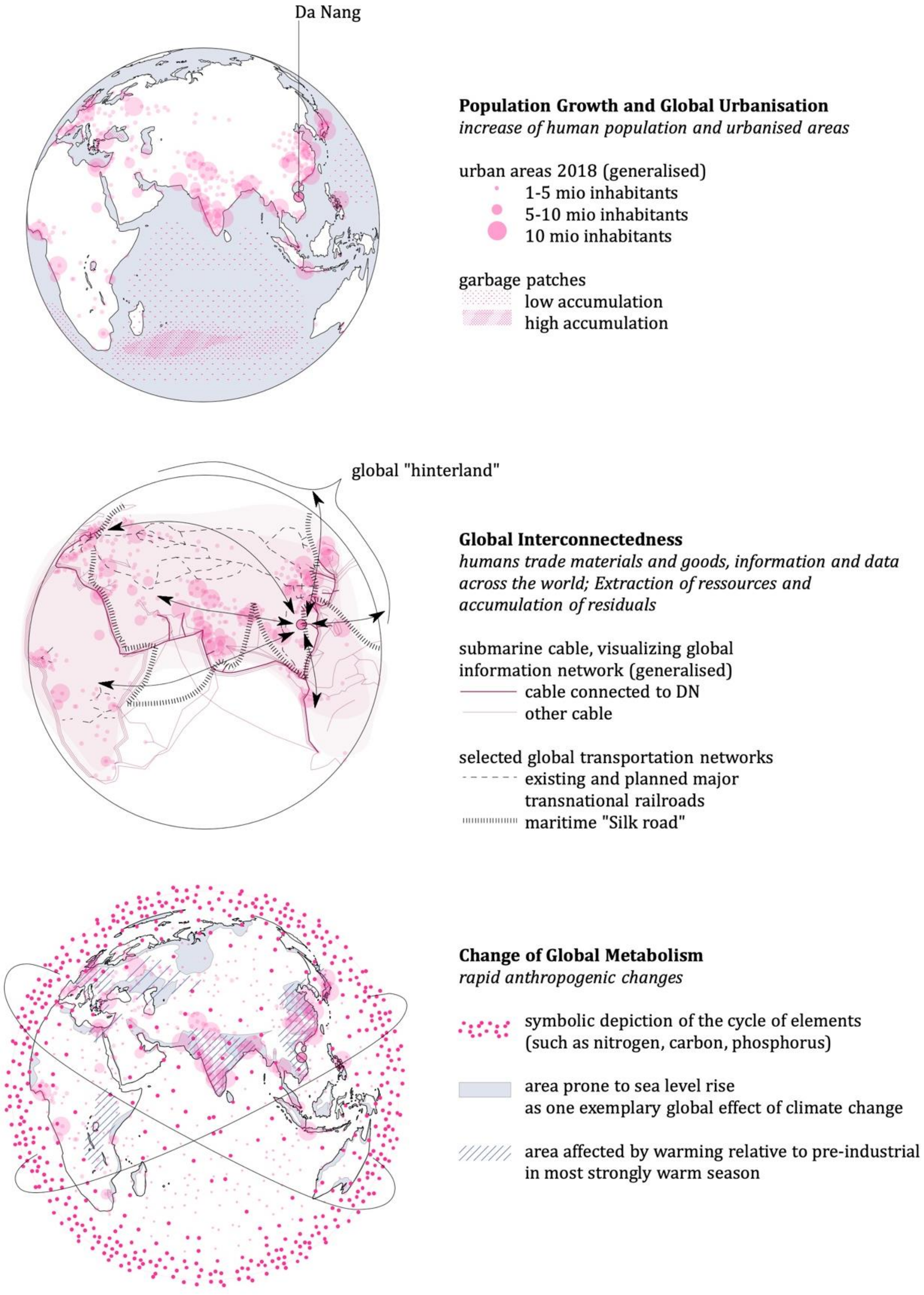


Figure 21 Da Nang in relation to global urbanisation and alteration, generalised and selected features (Burke et al., 2018; IPCC et al., 2018; Law et al., 2010; Nantulya and The Mercator Institute for China Studies (MERICS), n.d.; PriMetrica, Inc, 2019; United Nations, Department of Economic and Social Affairs, Population Division, 2019)

6.3.1 Rapid changes

6.3.1.1 Alterations of land cover

Vietnam's population is still growing rapidly, resulting in ongoing land turnover for agriculture, infrastructure and urbanisation. Agricultural land use has expanded significantly, going from under 20% of the total territory to almost 40% (World Bank, 2020).

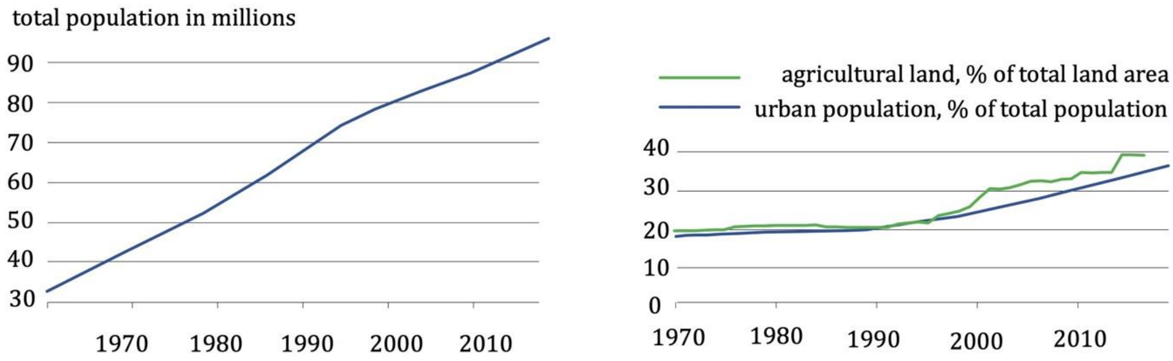


Figure 22 Growth of population and land use expansion in Vietnam (World Bank, 2020)

6.3.1.2 Increase in consumption of resources, dispersion/accumulation of residues and disruption of the cycle of elements

Overall, population growth naturally has led to an increase in total resource consumption in Vietnam. Economic growth since the Doi Moi reform has enabled significant improvements to living standards, access to basic services and increased resource consumption per capita. In 1993, only 14% of the total population used electricity for lighting, and only 17% of the rural population had access to potable drinking water. By 2016, 99% of the total population had access to electricity, and 70% of the rural population had access to clean drinking water, versus 95% of the urban population (World Bank, 2020). The share of undernourished people in Vietnam dropped from 16% in 2002 to 6% in 2019, while the prevalence of obesity in adults rose from 0.6% in 2000 to 2.1% in 2016 (FAOSTAT, 2020).

As laid out in Chapter 2.3.1, demand for natural resources, regulation of carbon emissions and the regenerative biocapacity is expressed by ecological footprint. In Vietnam, the footprint per capita has more than tripled, going from 0.6 gha in 1961 to 2.1 gha in 2016. Though population size also almost tripled, jumping from 33 million to 95 million people, the available biocapacity remained relatively stable (1.2 gha in 1961 and 1.0 gha in 2016) due to expansion and intensification of land use within the country. Ecological overshoot began in 1987, and the deficit accounts for -1.1 gha per capita in 2016. In comparison, Germany's ecological footprint peaked in 1979 with 7.3 gha/per capita and decreased to 4.9 gha in 2016, with a much higher total deficit of -3.3 gha/per capita (Global Footprint Network, 2019).

Increased resource demand has condensed in urban hubs such as Da Nang, and this has been met by connecting the region to the global market and expanding its metabolism, partly straining regional resource supply. Demand for domestic water is currently about 120 litres per capita per day and is expected to rise to 180 litres in urban areas and 120–180 litres in suburban areas (DOC, Da Nang, 2015). Increasing per capita and total demand will exacerbate current challenges of low supply during dry seasons for two reasons: 1) low river flow levels lead to salinity intrusion from the sea, affecting water quality (DOC, Da Nang, 2015); 2) overexploitation of underground water intensifies the lowering of groundwater level. Due to climate change and reduced water flows during the dry season, groundwater levels in Da Nang are expected to lower by 11 m after 2020 (MONRE, 2019, p. 53).

Regarding food systems, rising living standards and higher incomes lead to a change in diets and especially notably increased meat intake, which requires more resources and causes higher greenhouse gas emissions (IPCC et al., 2018, pp. 148–149, 327). Urbanisation has led to radical changes in the population's diet towards more processed products and foods rich in fat and carbohydrates, which has led to a rise in obesity (Socialist Republic of Vietnam, 2012, pp. 28–29). According to national statistics, meat intake rose from 1.8 kg per month per capita in 2010 to 2.2 kg in 2018 (General Statistics Office in Vietnam, 2018). According to FAOSTAT food balance sheets, meat intake is even higher at 5.6 kg in 2014 and 5.8 kg per month per capita in 2017. Low-income households consume much less meat (1.6 kg) but also fewer vegetables (1.2 kg) per month compared to high-income households (meat: 2.7 kg, vegetables: 2.3 kg), which indicates that both are relatively expensive goods. The same applies for fruit (0.6 kg compared to 1.4 kg). Instead, low-income households consume more rice (10.9 kg compared to 1.5 kg;

(General Statistics Office in Vietnam, 2018). Ongoing urbanisation will further take over prime agricultural land and likely affect the availability and accessibility of fruits and vegetables (see 8.1.2.3).

Population growth and increased resource consumption produce an accelerated metabolism and rapidly increasing waste management and pollution challenges (World Bank, 2020). It is expected that waste generation in Vietnam will double within 15 years. Vietnam is also among the top 10 countries worldwide most affected by air pollution and water pollution (World Bank, 2020).

Regarding the industry sector, the Urban Masterplan calculates 22–45 m^3/ha water per day and a generation of 0.3 tonnes of solid waste per day (DOC, Da Nang, 2015). Approximately 75% of solid waste is collected as mixed waste, with the rest being disposed of elsewhere, potentially polluting the environment. The city strives to significantly raise waste collection and the share of waste valorisation (see 7.3), but plans are still vague on how to manage the increasing amount of waste. Septic tanks pose an even greater challenge, with only 30%–40% being collected properly and vast amounts diffusing into receiving water bodies. Part of the septic tanks is connected to the drainage system, which is constructed as a combined system for both wastewater and rainwater in older parts of the city. More than 80 million litres of wastewater are generated daily, which is expected to quadruple to 320 million by 2030 (DAWACO, 2017).

A specific environmental issue of Da Nang is its dioxin contamination due to the use of Agent Orange during the Vietnam War. Agent Orange is an herbicide that was used and stored around the Da Nang military airbase. A recent study at the airbase's former mixing and loading area detected high dioxin contamination in the soils as a result of spillage and improper disposal of Agent Orange. The area encompasses a fishing pond and airbase garden, and those responsible for the area's cultivation and harvesting show highly elevated dioxin levels in their blood (Tran Van et al., 2019).

Like many cities, Da Nang's urban metabolism is a 'once-through' system in which nutrient and water cycles are not closed; as such, water and nutrients cannot be recovered despite being increasingly scarce resources. Instead, they are turned into residues that pose environmental risks. The way resources are consumed and disposed of in Da Nang contributes to the global disruption of the cycle of nitrogen, carbon, and phosphorus, leading to eutrophication of receiving water bodies, acidification of the sea and accelerated global warming. Da Nang has set ambitious goals and thoughtful strategies to tackle these challenges by becoming an 'Environmental City' (see 7.3.3).

6.3.2 Local negative implications

6.3.2.1 Degradation of biodiversity

Impact on local biodiversity is difficult to evaluate as it has not been assessed and monitored over long periods in Da Nang. Current explorations and conservation measures focus on remaining forests and the coastal reefs. Previous land turnover has reduced habitats, particularly in the lowlands of Da Nang.

Due to planetary urbanisation and global interconnectedness, local actions impact the biosphere's integrity on a global scale (see 2.2.2). A recent study localised driving forces for biodiversity losses and assessing regional 'biodiversity footprints' (Wilting et al., 2017). Losses are quantified in relation to land use and greenhouse gas emissions associated with the production and consumption of traded goods and services. The impact of land use affects habitat replacement through agriculture, urbanisation and fragmentation. The average footprint in Vietnam is estimated to be around 0.6 per capita; 82% of this footprint is caused within the territory, and 18% are externalised due to the import of products or services. The overall footprint is currently below the world average, which is estimated to be 0.8% per capita. Additionally, Europe, North America and Japan cause further biodiversity losses outside their territories. In Vietnam, 66% of the footprint is caused by land use (cropland 26%, pasture 14%, forest land 2%, urban area < 1%, infrastructure 5%, encroachment 4%, fragmentation through cropland 1%) and 34% by greenhouse gas emissions. The majority of losses (46%) are connected to food consumption. The high share of food accounting for biodiversity losses occurs in many countries regardless of income level and can be explained by the relationship between food production and land use (Wilting et al., 2017).

Overall, compared to the world average, Vietnam is not currently among the leading drivers of biodiversity loss, and the territory of Da Nang hosts comparably 'untouched' natural areas. However, the dynamic development of Southeast Asia foretells significant future losses if not managed more sustainably.

Regarding regional and local levels of biodiversity, the available planning documents do not directly indicate the extent to which the needs of local species that live within the lowlands are considered.

6.3.2.2 Climate change

Vietnam is considered one of the countries most affected by climate change. Its location along the South China Sea makes it very vulnerable to sea-level rise and coastal flooding (IPCC et al., 2018, p. 231). Between 1958 and 2014, the average annual temperature increased about 0.62 °C. Moreover, the highest daily temperature sharply increased by 1 °C/10 years (MONRE, 2019, pp. 44–45).

Annual rainfall has decreased in Northern Vietnam and increased in Southern Vietnam. Da Nang lies at the estuary of the large Thu Bon – Vu Gia basin (see 6.2), which has rapidly changing flow patterns. Average flow during flood season currently accounts for about 1,974 mm and is expected to rise to 2,628 mm by 2035 – an increase of 33%. During dry season, average flow is expected to further decrease by 3% from 937 mm to 911 (MONRE, 2019, pp. 52–53), which further exacerbates seasonal weather extremes of urban flooding and droughts.

The Central Coast has experienced the greatest water level rise in the country at 4 mm/year between 1993 and 2014 (MONRE, 2019, pp. 44–46). As a coastal city, sea-level rise poses a major threat for Da Nang. According to climate change scenarios, by 2100, Da Nang may lose about 4.1% of its current territory. Areas potentially most affected are prime business and tourism hotspots (Thanh et al., 2017).

Regarding agricultural production, it is estimated that sea-level rise will affect up to 40% of rice production area in regions such as the Mekong Delta, with rising temperatures posing an additional threat. Crop yields will likely decline by approximately 10% by 2065 (MONRE, 2019, p. 54).

7 ANALYSIS OF DA NANG'S PLANNING FRAME WITH RELEVANCE TO PGI

The following chapter outlines the existing planning system, which conditions considerations for a potential PGI as well as the visions and goals in existing plans. Planning content is examined for overall goals as well as for regulations and developmental directions relevant to PGI in terms of green spaces, urban agriculture and infrastructure development.

First, the general planning system in Vietnam is described (7.1). The relevant content of major planning frameworks on the national level, namely the Socio-Economic-Development Strategy and the national Urban Masterplan strategy, are outlined. A specific feature of Vietnam's planning strategy is issuing a National Food Security Strategy. In addition, internationally agreed goals are described (7.2). Additionally, relevant content of the Socio-Economic-Development Strategy, the national Urban Masterplan strategy and the local environmental city plan is outlined (7.3). The chapter is rounded off by describing urban transformation processes and the handling of land use rights, with a focus on green space development (7.4). After this, current challenges and possibilities in Da Nang are summarised and recommended planning strategies are reviewed. Again, the focus lies on green space development and how green spaces are currently utilised to tackle existing challenges (7.5).

7.1 Planning System Vietnam and Da Nang

As Vietnam is a unitary country, land is owned and managed by the state, and central agencies largely determine urban development through national ministries. Overarching planning direction is determined by the Socio-Economic Development Plans (SEDP), and other overarching thematic strategies correspond to the SEDP.

Da Nang is one of five centrally controlled cities where general (Master) urban planning and subsequent zoning and detailed planning are applied. The Masterplan is prepared by the Department of Construction (DOC) and is further developed in a cooperative process with the Department of Planning and Investment (DPI) and the Department of Natural Resources and Environment (DoNRE; (Thanh et al., 2017).

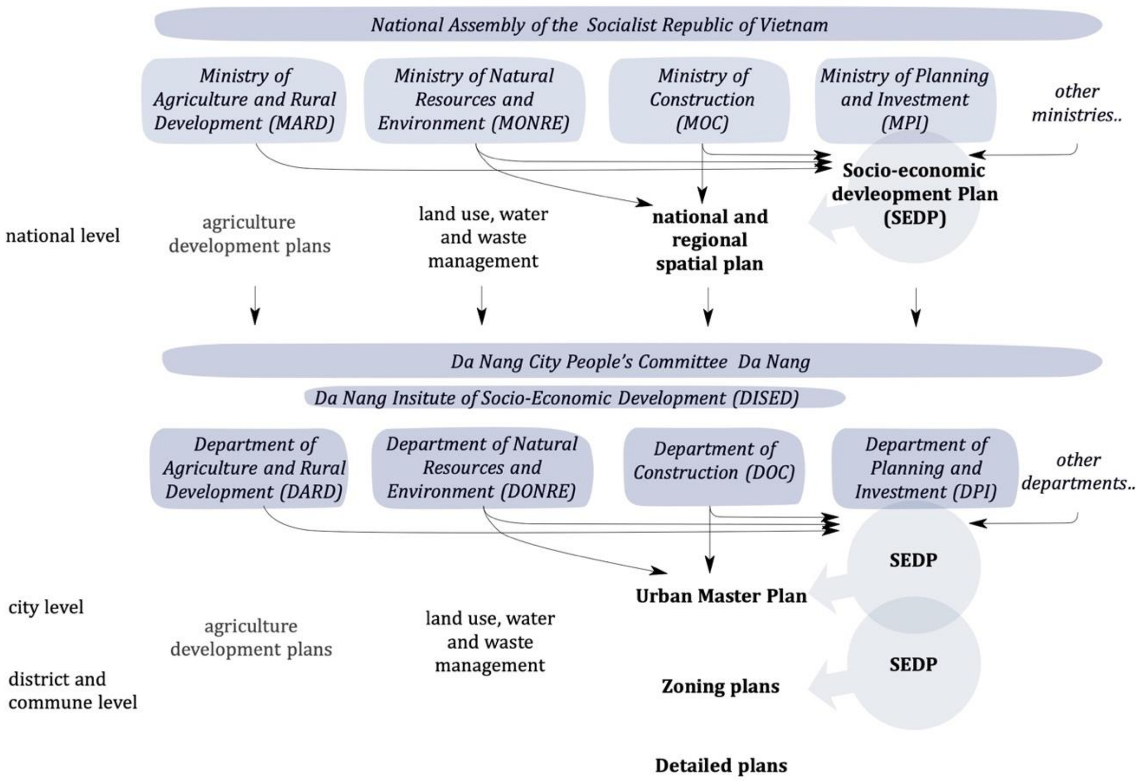


Figure 23 Main administrative bodies constituting urban development and spatial planning

7.1.1 Vietnamese Land Law

According to the ideals of the Socialist Republic, private ownership of land is not permitted in Vietnam. The state represents the entire people as owners of the land, and it uniformly manages land and leases land use rights (Law No. 45/2013/QH13).

Land law is a complex issue in Vietnam and reflects its transition towards a socialist-oriented market economy following the Doi Moi reform. Laws have changed in recent decades and have substantially impacted agricultural and urban development. Along with agricultural decollectivisation, the first land law was enacted in 1988 and recognised private land use for the first time (Nguyen, 2009). Further revisions in 1993, 2003 and 2013 strengthened farmers' land use rights. In 1993, land use rights were granted for 20 years, but they can now be obtained for 50 years. Land was not considered to have a value until a 1993 amendment that allowed possessors of land use rights to transfer, exchange, lease, inherit or mortgage their rights. Land prices have been regulated by the state since that time (Hansen, 2013).

As the state retains ownership, land is appropriated on large scales to pave the way for urbanisation and industrialisation. Between 2001 and 2010 alone, almost one million hectares of agricultural land were seized for urban development, for which farmers were compensated (Hansen, 2013) (see also 7.4.1).

7.1.2 Socio-Economic Development Plans (SEDP)

Urban development must be in line with the SEDP, which comprises a 10-year strategy and a five-year plan. The SEDP framework is issued at the national level and prepared by the Ministry of Planning and Investment (MPI), and it is subsequently concretised on the city level through cooperation between the Da Nang Provincial People's Committee and the local Department of Planning and Investment with contributions from other departments.

7.1.3 Urban Masterplans

Masterplans for entire cities must indicate 'the development objectives and driving force, population size, land area and basic norms on social and technical infrastructure of the city; (…) strategic environmental assessment; priority investment programs and resources for implementation' (Article 25, Law No. 30/2009/QH12 on urban planning).

The Masterplan assesses the city holistically as a social-ecological system, including natural conditions, the current socio-economic situation, land use, and technical and social infrastructure. It steers urban space development and guides functional areas such as agriculture and 'parks and open-space areas in the city'. Based on evaluating the natural urban environment, the Masterplan proposes solutions to prevent, reduce and remedy potential impacts on the population and natural ecosystems caused by urban planning (Article 15, Decree No.37/2010/ND-CP).

7.1.4 Zoning and Detailed Plans

Zoning plans must indicate

> functions for each lot of land; principles of organisation of space, architecture and landscape for the entire planned area; norms on population, land use and technical infrastructure for each street block; arrangement of social infrastructure facilities in response to their use needs; arrangement of the network of technical infrastructure facilities in each street suitable to each development period of the urban center; and strategic environmental assessment (Article 29, Law No. 30/2009/QH12 on urban planning).

Zoning plans demarcate plots by identifying the boundaries of construction and so-called 'red lines' (Article 19, No.37/2010/ND-CP, formulation, evaluation, approval, management of urban planning). Red lines are the boundaries for subdividing land for construction from lands for roads or technical infrastructure (Chapter 1, No.04/2008/QD-BXD on Vietnam building code). Zoning plans are prepared by the Department of Construction and coordinated with the other departments.

Detailed plans concretise these requirements for the entire planned area (Article 30, Law No. 30/2009/QH12 on urban planning) and are usually prepared by further developers (Thanh et al., 2017).

There are additional regulations to guide construction. In Da Nang, decision 47/2012/QĐ-UBND on architectural management of works describes architectural principles (e.g., style and colour of buildings, building materials) as well as further regulations of red lines and construction boundaries for public and residential buildings, including specifications for single districts.

7.2 Planning content at the national level

7.2.1 10-year Socio-Economic Development Strategy Vietnam 2011–2020

As of 3/2021, the SEDP 2020 remains in force as a new SEDP 2030 has not been published yet.

The Socio-Economic Development Strategy is led by the decision to 'continue promoting industrialization and modernization by developing quickly and sustainably; upholding the whole population's strength, building up our country to be industrial with a socialist orientation'.

The Strategy reviews the progress of the previous period, which is characterised by economic growth and improvement of 'people's physical and spiritual lives'. In light of economic globalisation and the financial crisis of 2008, the Vietnamese government expects that further processes 'of restructuring economies and adjusting global financial regulations will take place aggressively in association with new advances in science, technology and economical usage of energy and resources'.

The first objective is as follows: 'sustainable development is a foundation for fast development, and fast development is to create resources for sustainable development'. Emphasis is placed on ensuring sustainable economic development combined with implementing social advancement, equality and environmental protection. Another derivation is that the economy must be built up 'with increasingly high independence and self-control in the context of a more intensive integration into the world', which aims to strengthen domestic enterprise's competitiveness to control the domestic market and expand external markets.

Concrete socio-economic objectives include achieving an annual increase in GDP rate at 7%–8% and reaching a medium-high classification in the Human Development Index (HDI; see Box 3). Environmental objectives include raising forest coverage and implementing centralised systems for wastewater treatment. Goals for waste treatment rates are set at 95% for regular waste, 85% for toxic waste and 100% for hospital waste. Vietnam aims to actively deal with climate change and sea-level rise. Urban development is based on 'comprehensive, modern and environment-friendly infrastructure'.

Agricultural development goals include 'modernity, effectiveness and sustainability' along with economic growth. Irrigation systems will be modernised, and delta areas are encouraged to develop high-tech agriculture and pursue intensive rice cultivation.

7.2.2 Master Plan for Vietnam's Urban System Development to 2025 with Vision to 2050

The Urban Master Plan for Vietnamese cities up to 2025 and the vision for 2050 addresses infrastructure development, resource utilisation and 'urban landscape architecture development'. The plan states that 'urban systems' must be appropriately distributed throughout the country, ensure food security on the national level and foster 'urban-rural linkages'. Urban development must be 'stably and sustainably' built 'on the basis of suitable spatial organised planning; rationally utilise natural resources, surface land; energy saving, environmentally friendly and ecologically balanced'. Furthermore, construction of 'advanced social and technical infrastructure to meet specific needs, usages and to match with urban development strategies' is emphasised, along with making rational use of natural resource and land. The plan confirms goals such as raising access to freshwater to 90% of the urban population.

There is also a paragraph dedicated to landscape architecture that states,

> landscape architecture in each region and urban area should have a proper identity, in line with natural and economic conditions; population – society; scientific and technical qualifications; cultural and historical traditions of the local region and new requirements for development. The overall architecture of each city should harmoniously combine renovation and new construction, environmental innovation and traditional cultural architecture. (Decision No. 445/QD-TTg of the Prime Minister on the adjustment of Urban Master Plan orientation of cities system in Vietnam to 2025 and vision to 2050)

7.2.3 Green Growth Strategy Vietnam

'Green growth' is an established development theme in Southeast Asia (ADB, 2019).

In 2012, the Ministry of Planning and Investment proposed a Green Growth Strategy as an overall development model in Vietnam to 'ensure, fast, efficient and sustainable growth' and contribute to implementing the national climate change strategy (Decision No. 1393/QĐ-TTg of the Prime Minister). Strategic tasks are 1) the reduction of greenhouse gases, 2) 'greening' of production through efficient use of natural resources and environmentally friendly procedures, and 3) a 'greening' of lifestyle by promoting sustainable consumption while creating high living standards. Lifestyle greening is seen in context with rapid and sustainable urbanisation coupled with certain waste and wastewater collection and treatment rates.

The strategy describes 17 solutions for different strategic fields ranging from communication and education to urban planning, resource utilisation and infrastructure development to implement these strategic tasks. Solution No. 5 addresses agriculture and suggests the development of sustainable organic but also competitive agriculture based on low greenhouse gas emissions. It aims to close resource cycles by reusing by-products and waste to produce animal feed and other materials. Other solutions reiterate the recycling and reuse of wastes (8b) and the development of sustainable infrastructures, including irrigation systems (9c).

While the strategy specifies that Urban Masterplans should shift agricultural production sites to rural areas (5), it also promotes conserving and restoring degraded ecological systems (8d) and the greening of urban landscapes (11d). Regarding sustainable urbanisation, Urban Masterplans should 'prioritize the allocation of public land to expand the area of green space and water in urban areas'. Additionally, they should stimulate investments in green spaces in urban development projects and 'encourage communities, enterprises and households to mobilize resource for the greening of urban landscapes'.

The Da Nang Green Growth Strategy concretises the goals on a local level.

7.2.4 Food Security Strategy Vietnam

In 2009, the Government of Vietnam issued Resolution No. 63/NQ-CP on National Food Security, which was prepared by the Ministry of Agriculture and Rural Development (MARD). It is a response to the remaining issue of food shortages despite steadily increasing output, particularly regarding rice. At the time of the resolution, rice production exceeded domestic demand, leading to Vietnam's establishment as a major exporter. The resolution defines a general objective to 'ensure adequate food supply sources with an output higher than the population growth rate; to put an end to food shortage and hunger and raise meal quality' by 2020 with a vision towards 2030 (p. 50).

These objectives include

a) defining a specific amount of land for rice production, which is set at 3.8 million ha; this is calculated to produce 41–43 million tonnes annually for domestic demand and 4 million tonnes for export. Similar target values are defined for maize (1.3 million ha/7.5 million tonnes), fruit trees (1.2 million ha/12 million tonnes), and vegetables (1.2 million ha/20 million tonnes) as well as for animal husbandry (meat, dairy and fish). Areas protected for rice production are specified for each province, district and commune. Peasants are encouraged to continue rice farming by ensuring sufficient profit.
b) defining specific objectives to meet nutrition needs based on a daily calorie consumption of 2,600–2,700 kilocalories per person. Target values for average quantities for different food groups are defined as 100 kg of rice, 45 kg of meat, 30 kg of fish, 50 kg of fruits and 120 kg of vegetables per person per year, all of which must meet specific hygiene and safety standards.
c) ensuring that 100% of the population has access to adequate food anywhere and at any time.

Objectives for rice production are reflected in the land use Masterplan, with certain land areas being restricted for rice cultivation alone (Resolution 17/2011/QH13). According to processed maps of Kien Le (Le, 2020, p. 26), the restrictions also affect rice cultivation areas in Hoa Vang District, Da Nang.

The resolution also endorses an upgrade of infrastructure, particularly irrigation works for paddy fields with two rice crops as well as vegetable production sites, building an information system for food security, improving processing and trading, and increasing investments in scientific research on agricultural production and food security.

Finally, the resolution aims to develop 'food circulation systems' to 'creat[e] the conditions for every consumer to have convenient access to food in all circumstances' (pp. 53-54). Hence, the National Food Security resolution considers all process components of the food system and their interrelations at the national level. In particular, the relationship between production (i.e., ensuring land and efficient production modes) and consumption (i.e., meeting the national food demand) is acknowledged and emphasised.

Food security is also addressed in the National Strategy for Climate Change, prepared by the Ministry of Natural Resources and Environment in 2011 (No. 2139/ QD-TTg). Here, maintaining reasonable agricultural land and ensuring local food security is reinforced.

With a statement on their website, MARD responded to the ongoing COVID-19 crisis and reiterated the need to ensure food security under any circumstances (MARD, 2020).

> Food security becomes a more crucial issue for every nation, particularly in the context of politic instability, negative impacts of climate change and unconventional security, for example, a global pandemic. (Prime Minister Nguyen Xuan Phuc, 15th of April, 2020 in MARD, 2020)

In the past 10 years since the strategy's implementation, agricultural production increased, and the malnutrition rate has been reduced (see 6.3.1.2). Vietnam now ranks 54th among 113 countries on the Global Food Safety Initiative.

7.2.5 National Nutrition Strategy

In addition to the National Food Security Strategy, Vietnam ratified a National Nutrition Strategy for 2011–2020 with a vision toward 2030 to address quantity and quality in diets (No: 226 /QD-TTg). The strategy emphasises reducing malnutrition among mothers and children, decreasing the number of people who are overweight or obese and promoting micro-nutrient statuses. While in past years achievements have been made in reducing food shortages and malnutrition, large-scale urbanisation and the reduction of agricultural land that provides a livelihood for the population have become major challenges. Moreover, substantial changes have occurred in urban population diets towards more fat, carbohydrates and processed products, which is linked to rising obesity levels (Socialist Republic of Vietnam, 2012, p. 28).

7.2.1 Reflection of internationally declared goals – SDGs and the New Urban Agenda

While green infrastructure planning as well as urban food system planning have their roots in American and European planning contexts and have not yet been absorbed in the Asian context, there is common ground through the internationally declared SDGs and the New Urban Agenda of the United Nations (see Box 5), which Vietnam is particularly committed to.

Vietnam nationalised the SDGs in May 2017 with a National Action Plan of 115 Vietnam SDGs (VSDGs) to implement the 2030 Agenda and has since prepared 'Voluntary National Reviews' to evaluate achievements and analyse policy gaps and potential challenges. Sustainable principles are mainstreamed into the Socio-Economic Development Strategy (see 7.2.1). Similarly, the UN Conference on Housing and Sustainable Urban Development provides guidance for evaluating and directing urban development in Vietnam. In 2016, the national UN-Habitat office and the Ministry of Construction prepared a National Report for Habitat III.

7.2.1.1 Goals related to food security

In terms of SDG 2 'zero hunger', the latest SDG Voluntary National Review refers to the reduction of food shortages and malnutrition but indicates that nutritional status disparity remains among social groups and geographical areas (Socialist Republic of Viet Nam, 2018).

The National Habitat III Report explicitly encourages enhancing urban and peri-urban food production as a key factor of poverty reduction and social policies. The report acknowledges that 'urban and peri-urban agriculture plays an important role in the urban food system' (Socialist Republic of Viet Nam et al., 2016, p. 30) and describes a shift from low-profit rice farming to high-profit fruit production to meet the demand of local consumers, thus notably contributing to household income, livelihoods and food security. However, rapid urbanisation and land speculation is recognised as threatening the persistence of the tradition of urban agriculture.

> Urban agriculture in peri-urban areas and the natural environment are threatened by rapid and unplanned expansions of urban areas, which leads not only to the conversion of farm land into residential and industrial land but also to the filling of wetlands, which play a key role in irrigation and drainage. (Socialist Republic of Viet Nam et al., 2016, p. 32)

This paragraph highlights the multifunctional uses of urban agriculture in urban systems and its potential to mitigate the effects of climate change.

7.2.1.2 Goals related to sustainable urban development, green space planning and climate change adaptation

Regarding SDG 11 'sustainable cities and communities', the SDG Voluntary National Review underlines recent rapid urban development and improvements in the housing situation. The implementation of SDG 11 is closely linked with SDG 13 'climate change action' due to the severe effects of storms, flash floods and droughts which make water drainage a central issue (Socialist Republic of Viet Nam, 2018, pp. 60–61). While the importance of social, traffic, supply and disposal infrastructure is highlighted, dedication to providing access to green and public spaces is not mentioned specifically (SDG 11.7).

The section on 'environment and urbanisation' in the National Habitat III Report stresses that urban expansion occurs in low-lying floodplains by filling land up to 2.5 m, which reduces retention space for accumulating rainwater during rain seasons. The report explicitly mentions the case of Da Nang. The report reflects efforts to expand drainage capacity (Socialist Republic of Viet Nam et al., 2016, pp. 51–52).

The section 'urban planning and management' specifically states that 'protection of green spaces and wetlands is critical to developing liveable cities' and achieving sustainable urban development (p. 65). The report states that the positive contribution of urban public spaces has been increasingly acknowledged, but it also notes a decline in green and especially blue spaces in urban areas as well as a lack of management and inconsistent definitions of public spaces and related policies (p. 65-66).

7.2.1.3 Goals related to participatory planning approaches

Collaborative and participatory planning is a key principle of green infrastructure planning and is of particular importance to integrating the social practices of urban agriculture. This principle is linked to SDG 16.7, which aims to 'ensure responsive, inclusive, participatory and representative decision-making at all levels' (United Nations, 2015). In the latest SDG Voluntary National Review, Vietnam claimed to have made progress towards SDG 16 via improved information access and reforms to its 'administrative structure from the central to the grassroots level' (Socialist Republic of Viet Nam, 2018, p. 79).

The New Urban Agenda envisages human settlements that 'are participatory, promote civic engagement' and that create

> a sense of belonging and ownership among all their inhabitants [and] prioritize safe, inclusive, accessible, green and quality public spaces (…) that enhance social and intergenerational interactions, cultural expression and political participation (United Nations, 2017, p. paragraph 13b).

In this context, the National Habitat III Report refers to City Development Strategies that were introduced to enhance participation mainly in terms of collaboration with the donor community. In this regard, it is stated that 'city officials were initially unfamiliar with participatory planning and consultation of city stakeholders'. The report concludes that the existing planning regime, which was rooted in a market economy with a socialist framework, is strained by the requirement of responding to the demands of urban residents for a liveable city and conserving its public spaces and cultural heritage. Hence, planning institutions and procedures need to adapt to a more participatory approach and make plans that are more responsive to local conditions (Socialist Republic of Viet Nam et al., 2016, p. 67).

7.3 Planning content at the level of Da Nang City

In line with national frameworks, urban development in Da Nang City is mainly based on the Socio-Economic Development Plan (7.3.1) and the Urban Masterplan to 2030 (7.3.2). Moreover, Da Nang has adopted the Environmental City Plan (7.3.3; (Thanh et al., 2017, pp. 28–31). The documents are analysed to retrieve the overall development direction and vision. Moreover, specific goals and measures with a potential relation to PGI in terms of green spaces, aspects related to urban food systems and urban agriculture are extracted. Also, factors that influence the urban metabolism in terms of its water and nutrient cycles are analysed.

7.3.1 Socio-Economic Development Plan (SEDP) Da Nang towards 2020

The national Socio-Economic Development Plans are concretised at the city level. In the eyes of the Vietnamese government, Da Nang is an urban centre with strategic relevance in the region. Da Nang's expected GDP growth rate is far above that of the country overall with 12%-13% annual increases predicted and is expected to reach 4,500–5,000 USD per capita.

The objectives and criteria of Da Nang's Socio-Economic Development Plan are cross-checked with its overall strategy to become an 'Environmental City' (see 7.3.3). Accordingly, objectives aim to develop the waste recycling industry and to achieve a recycling rate of 70% and 25% reuse of water. In addition, the goal is to treat 100% of domestic and industrial wastewater.

The Socio-Economic Development Plan explicitly includes objectives for green space development that were originally formulated in the Environmental City Plan. For the period between 2011–2015, the following goals were set: 'Expand the urban green space (including landscapes, parks, flower gardens, trees on streets and at schools) in a reasonable layout and species which is expected to reach 3–4 m^2 per person'. For the period between 2016–2020, the objective was raised to provide 9–10 m^2 per person, as compared to the 10–12 m^2 per person stated in the Urban Masterplan (see 7.3.2).

Moreover, implementing measures for forest biodiversity conservation, strengthening the management and protection of forests and accelerating afforestation to increase forest coverage up to 50.6% are planned.

7.3.2 Urban Master Plan Da Nang City to 2030 and vision to 2050

7.3.2.1 Overarching vision and urban development principles

The main objectives of the Urban Master Plan (DOC, Da Nang, 2015) are to 'appropriately build the city with approved planning toward sustainable development and competitive advantages' and to integrate the objectives of other planning frameworks, namely the SEDP and the Environmental City Project. The Urban Master Plan thus serves as a foundation for implementing detailed plans for construction and investment and as a legal basis to control and manage urban development.

The Urban Masterplan proposes a development model for Da Nang which follows the principle of 'integrating with the central urban chain, natural landscapes and ecological system; exploring potentials of natural conditions, culture and history'. It orients the city's spatial structure and infrastructure development and proposes functional zones such as urban areas, industrial areas, agricultural areas and natural conservation.

Da Nang faces a rapidly growing population which is handled by expanding urban areas by constructing 'satellite urbans, towns, communal centres, communal clusters, and develop large-scale infrastructure to gradually establish the urban cluster of Da Nang'.

7.3.2.2 Balancing land use between urban expansion, agriculture and the natural system

Urban growth must be managed for Da Nang's territory, which contains parts that are unsuitable for development due to steep topography in the hinterland and flood-prone plains. These low-lying plains are characterised by fertile soils with favourable conditions for agriculture and are predominantly used as paddy fields (see Figure 24).

In this context, balancing land uses is a central task of the Urban Masterplan. The Urban Masterplan connects to the National Food Security Strategy and scrutinises the potential turnover of agricultural land: 'the calculation of land use must be very tight to ensure efficient use and for the right purpose of socio-economic development of the city' (DOC, Da Nang, 2015, p. 72).

The Urban Masterplan has defined criteria for allocating construction land. Areas favourable for construction (6.6% of the total area) have flat terrain conditions which are beneficial to hydrology and geological stability as they have low flood groundwater level and low flood risks. At the same time, the Urban Masterplan defines farmland with low productivity as less fertile; acidic; or characterised by mangroves, mudflats or marine riparian wetlands. Construction land defined as less favourable has relatively flat terrain with only slight slopes and medium water level or is farmland with medium productivity. Entirely unfavourable land for construction is characterised by a slope above 20% (representing 32.6% of the total area), high groundwater level and highly productive farmland. Unfavourable is also land prohibited for construction of clearance corridors for airports, national security or defence areas and protected areas. These unfavourable areas account for 44.4% of the total area.

Balancing land use is an ongoing process. According to the Urban Masterplan, from 7,948 ha agricultural land in 2015, 3,064 ha of agricultural land – less than half – is to remain; this figure is a revision from a prior version of the plan which stipulated urbanisation of all the low-lying plains and hence near-total elimination of large-scale agriculture in the city region (see Figure 24).

Urban expansion is also seen in the context of the natural system. Natural preservation areas must be protected and monitored based on a 'Biodiversity inspection network' (p. 235).

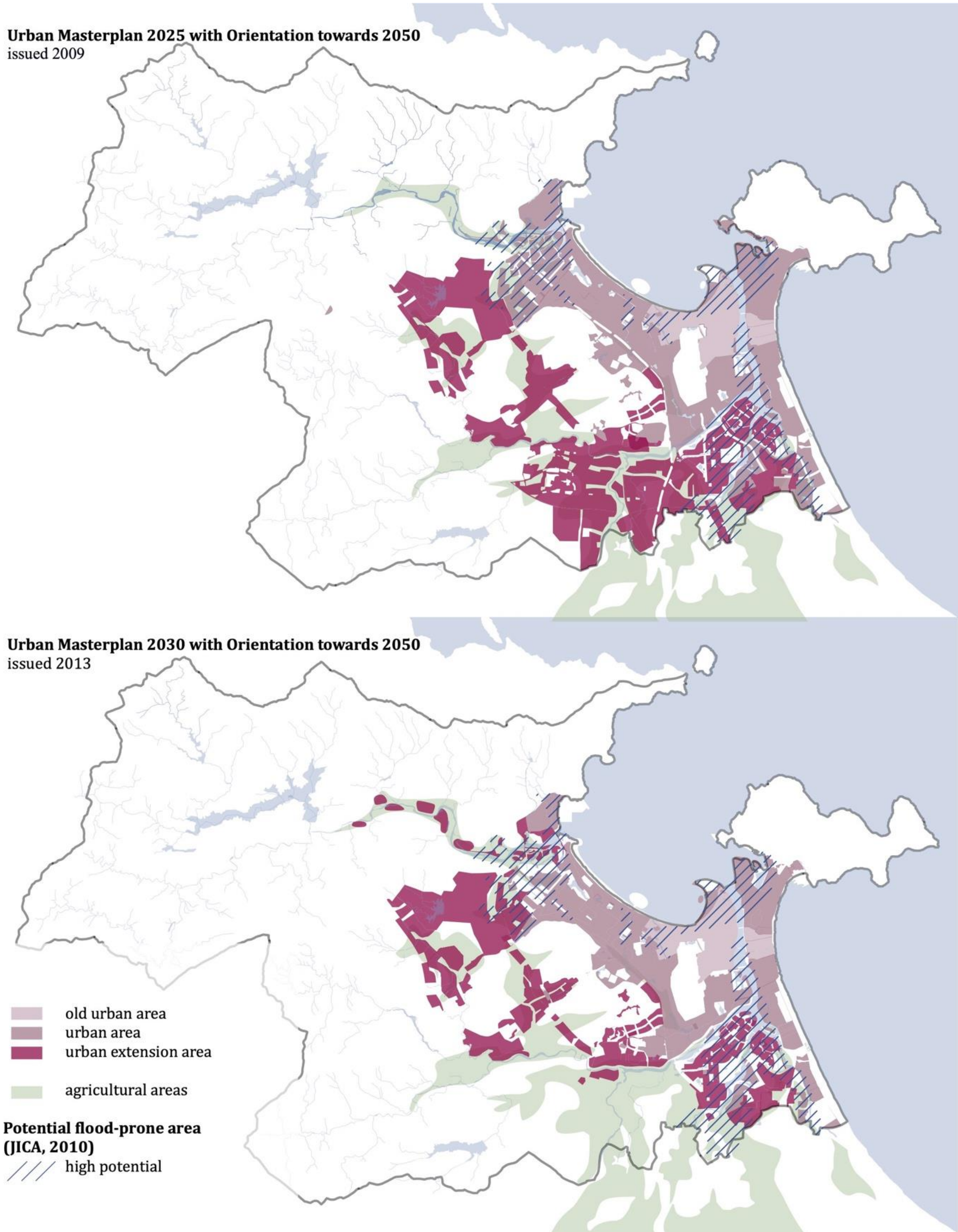


Figure 24 Urban Masterplan 2009 and 2013, digitalised from .jpgs, compared to existing land use based on aerial picture interpretation to distinguish urban extension area. Rough digitisation of agricultural land.

7.3.2.3 Development of the agricultural sector

Forestry, fisheries and food processing are important industries in Da Nang, with seafood being a major export good. The Urban Masterplan endorses further efforts in processing and exporting goods and diversifying the product range.

Moreover, the Urban Masterplan aims to develop a diversified, 'clean' agriculture sector, with a specific focus on clean vegetables, fruits, bonsai, flowers and cattle; this focus is also a reaction to previous concerns regarding food safety (see 8.1.1.2). The plan further sets the goal of meeting the needs of Da Nang's citizens, thus acknowledging the relevance of regional agriculture in contributing to local food security. The share of agriculture in the city's GDP is declining due to an overall transition toward the service sector and decreased agricultural land. Given this context, the Urban Masterplan values agriculture's intermediate role in contributing to Da Nang's economic growth via linkages to tourism and service development.

To 'rationalise the distribution of manpower between rural and urban' areas, promoting the development of 'urban agriculture' is one of several measures intended to create employment opportunities (p.72). This goal must be seen in the context of land appropriation from farmers in the course of urbanisation as farmers not only lose their land but also their occupation (see 7.4.1).

The Urban Masterplan also assesses the potential environmental impact of urbanisation and ways to alleviate this. The 'farming-village urban protection' (p. 210) section deals with protecting surface and groundwater and preventing pollution by avoiding overuse of pesticides and fertiliser and by properly operating wastewater and solid waste treatment systems.

7.3.2.4 Landscape architecture and green space development

The Urban Masterplan has a section dedicated to 'green open urban spaces' (p.82), which is seen as a central aspect to developing Da Nang as a sustainable, environmentally friendly and liveable place. An additional section deals with 'structuring landscape architecture space' (p.126), which is understood as the reasonable arrangement of functional areas. This understanding of landscape architecture is not limited to green spaces but refers to urban design in general.

A variety of green open spaces are planned, including 'gardens; small, medium and large parks; green avenues on the main roads in urban, coastal, riverbanks' (p.82) as well as monuments, cultural facilities (e.g., museums, libraries) and sport facilities (e.g., golf courses, tennis, swimming). The envisioned structure of green spaces is meant to take advantage of the existing water-related geographical features of lakes, rivers and coastline.

Renovations and upgrades to existing parks are planned, and land will be allocated for developing new parks and gardens alongside urban growth. Large parts of the 'old urban land' are very dense and mostly built up without any green spaces, with the exception of open spaces along the coast and the Han River and green spaces along intra-urban water bodies, such as the 29-3 Park or the Cluster Garden Centre Axis in Lien Chieu District.

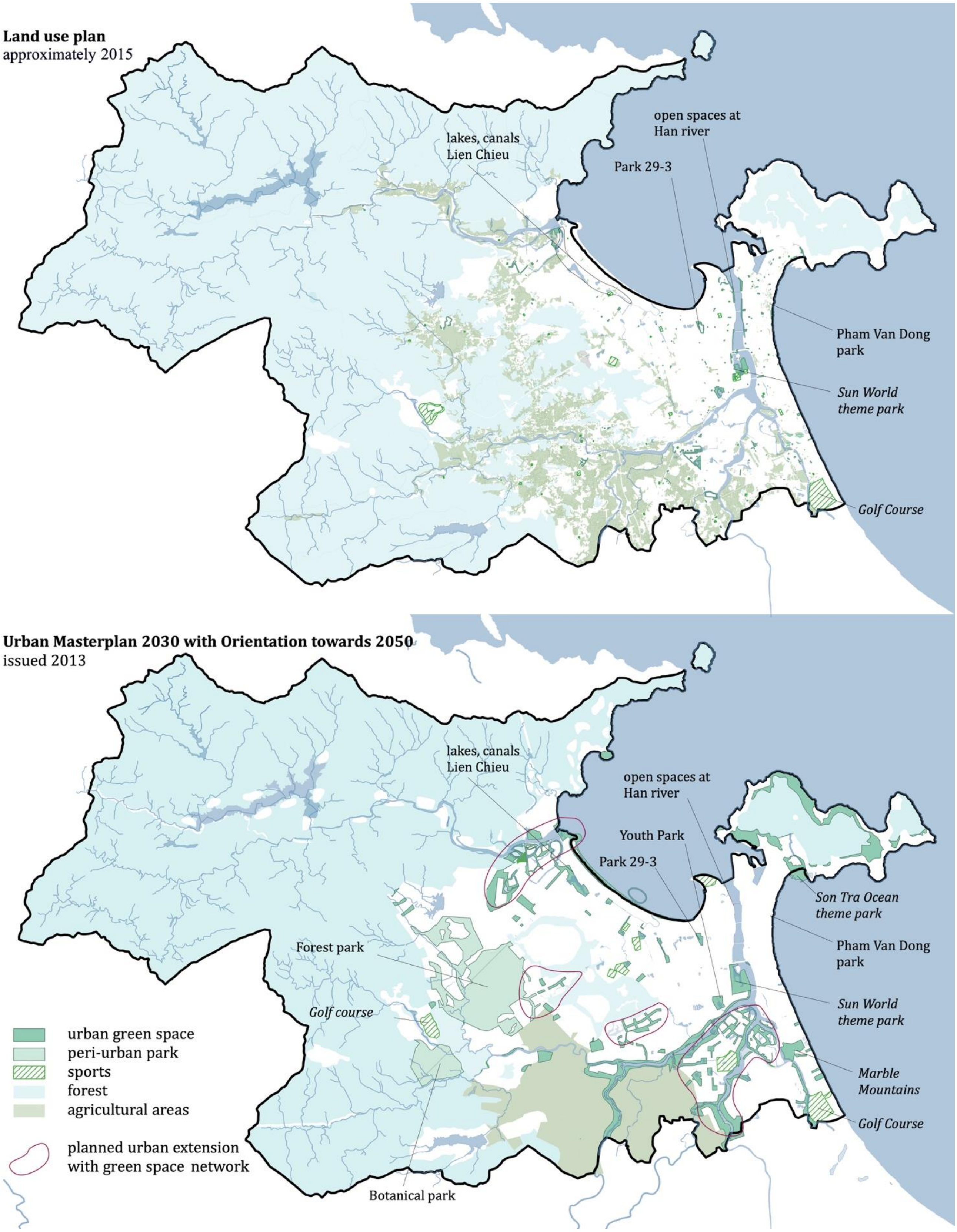


Figure 25 Existing green spaces in Da Nang and planned green spaces according to the Urban Masterplan

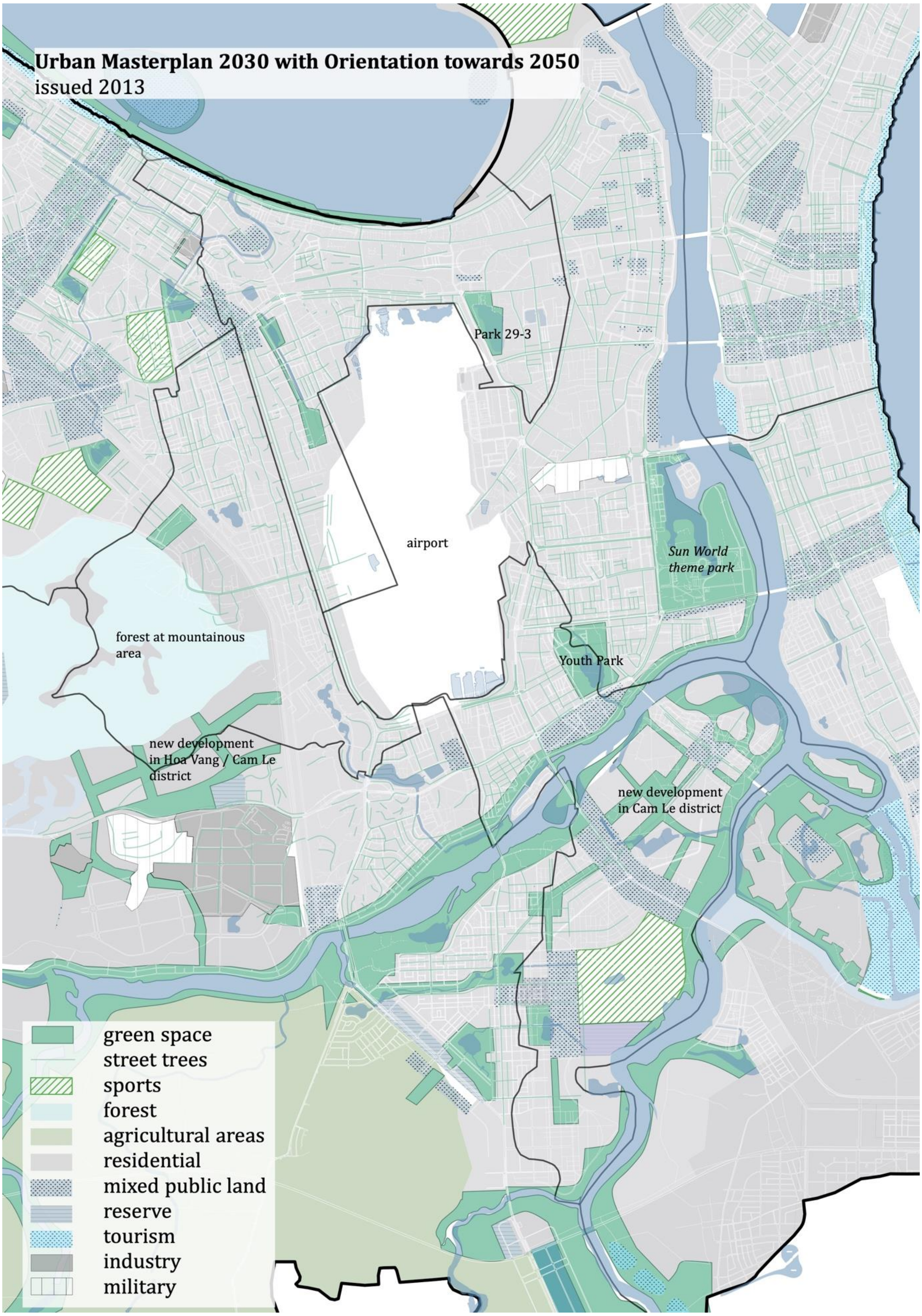


Figure 26 Zoom in to Urban Masterplan and depiction of green space layout. Digitised from jpg. image of Urban Masterplan, road network by OpenStreetMap Contributors, administrative boundaries by GADM, street trees based on visual aerial image interpretation

The average amount of green space per person is estimated to have been around 5.02 m² in 2010, when the population comprised 890,490 people. Accordingly, the total amount of green space was around 450 ha in 2010 and covered the following:

Table 4 Composition of green spaces in 2010

Area covered by treetops[18] of street trees	23%	102.8 ha
Public parks and flower gardens managed by the city	4.57%	20.4 ha
Playgrounds managed by the districts	3.59%	16 ha
Nurseries	2.39%	10.6 ha
Treetop areas at public institutions such as offices, schools	7.38%	32,9 ha
Private gardens	59%	263.7 ha
in total	100%	446.4 ha

The Urban Masterplan intends to increase the extent of green space and set the minimum green space standards at 7–8 m² per person by 2015 and 10–12 m² per person by 2020 (p. 86).

Due to rapid population growth, major transformation potential is seen in the design of residential urban extension areas. The Urban Masterplan intends to 'build 100 focusing points (around 100 ha) of shade trees, flower gardens in residential areas and encourage families to take advantage of the space in the yard to plant trees' (p. 100). The Urban Masterplan's cartographic representation depicts urban extension areas equipped with an integrated network of public green spaces (see Figure 25 and Figure 26). Moreover, the Urban Masterplan aims to activate the potential of privately owned plots by reducing share-lot housing and increasing the share of apartments and houses with gardens. The Urban Masterplan lists a number of parks, some of which are amusement or theme parks or touristic resorts, which are not accessible free of charge, such as the planned Son Tra Ocean Park, Ngu Hanh Son Cultural Park at Marble Mountains, the Botanical-Zoological Park, and Hoa Phong and Hoa Phu golf course. In total, these parks account for 1,250 ha (p. 105). The map indicates that some of the parks are located in the peri-urban area demarcating mountainous forests. The Urban Masterplan takes all of these parks into account when defining the target amount of green space and calculating green space standards per person.

Another central project is the expansion of trees. The city plans to equip 100% of the roads with ornamental and shading trees. To increase the level of urban green space, the Urban Masterplan examines currently 'grey surfaces' of different land use types regarding purpose and ownership to tap the city's full potential for maximum green space. It promotes tree planting and maintenance in areas such as 'industrial zones, solid waste treatment areas, wastewater treatment areas, tourist areas, cemeteries, hospitals, schools, offices, residential areas' (p. 86-87) and also plans to green so-called 'grey' or 'hard' infrastructure such as the safety rail corridor, bridge pavements and river trails.

Another focus lies on fostering a culture of nurseries to provide seeds and plants locally in order to maintain and expand urban green spaces and provide flowers for ornamental decoration for festivals. Nurseries can serve as the 'experimental garden of the city and a research nursery for students' (p. 86). Several nurseries are planned, including a large 50 ha location in Ninh Hoa, a smaller 5 ha location in Hoa Tho and further 'satellites' and temporary nurseries.

7.3.2.5 Flood prevention and drainage

The Urban Masterplan addresses Da Nang's increased risk of urban flooding (see 6.3.2.2) by defining a range of strategies and measures. The aspect is analysed because of the potential application of blue-green infrastructure (3.5.2).

As an overall strategy, the city aims at 'improving the drainage of main sewers, utilising and upgrading the existing culverts to enhance the ability of the sewer lines, diverting drainage culverts to switch among the

[18] Trees are classified according to the size of the coverage area of the treetop, with newly planted 2 m²/tree, classification I: 16.5 m²/tree, classification II : 26.5 m²/tree and classification III: 36.5 m²/tree (p.32)

basins, and investing in new culverts from the existing reservoir regulators to adjust culverts to reduce flooding in the area'. Da Nang's territory is subdivided into several sub-basins with measures specified to improve the quick release of rainwater into the Han River and Co Co River or into the sea. Additional pump stations are planned in areas affected by tidal cycles. The Urban Masterplan also includes dredging and regulating the river system upstream of Da Nang while carefully monitoring sedimentation and erosion processes. The targeted use of crops to stabilise riversides is also seen as an option for flood management.

Moreover, dikes and embarkment systems will be upgraded to tackle the challenges of rising seawater levels, storms and associated flooding. The total length of planned river embankments accounts for 74,400 m, of which 36,900 are planned as 'hard' embankments, while the rest will be 'soft' embankments with Vetiver grass.[19] All embankments will be lined with trees, and existing ecosystems will be rehabilitated.

This strategy will regulate rainwater as quickly as possible outside the system as Da Nang into receiving waters at the coast. The role of green spaces in infiltrating surplus rainwater and providing retention space at riparian landscapes does not seem to be a focus.

7.3.2.6 Infrastructure development

The Urban Masterplan bundles sectoral infrastructure plans by forecasting infrastructure needs and defining standards. Domestic supply and disposal are separated between urban and rural populations. Domestic water demand is expected to be 180 litres per person per day in urban areas and 120–180 litres per person per day in suburban areas by 2030. The goal is to supply 100% of the urban population and 70% of the rural population with centralised water. Regarding sanitation, the goal is to treat 90% of wastewater before being discharged into receiving water bodies and to collect 100% of solid waste, which is expected to amount to 1.3 kg per person per day. Regarding industry, the Urban Masterplan calculates 22–45 m^3/ha of water use per day as well as generation of 0.3 tonnes of solid waste per day.

7.3.3 Environmental City Plan for Da Nang

The prime vision of Da Nang was to become an 'Environmental City' by 2020 based on decision No. 41/2008/QD-UBND from 21 August 2008. An Environmental City is a 'city without environmental pollution and degradation where people live in harmony with nature'.

This strategy was a response to the Summit Conferences of the United Nations and the Brundtland Report (see also United Nations General Assembly, 1987). The strategy is rooted in addressing the challenges of environmental pollution and declining natural resources in Da Nang, which arose with urbanisation, industrialisation and modernisation (see 6.3). The framework for the *Environmental City* was drawn from national environmental protection programmes in Sweden, the 'eco-city' initiative of Japan and criteria for environmental city development in Vienna. Overall goals are ensuring water and air quality, providing a safe and healthy environment, preventing environmental pollution and degradation and increasing awareness of environmental protection. The strategy is structured into different periods with specific goals to manage concrete environmental problems such as landfill pollution and building new wastewater treatment plants. The objectives have been integrated into the SEDP.

A key feature of the plan is metabolic processes and related infrastructures. Adherent objectives include specific treatment rates for wastewater and solid waste; these have been updated in the more recent Urban Masterplan and SEDP.

After its initial declaration in 2008, the strategy was refined through the Integrated Development Strategy for Da Nang (DaCRISS), which was created by the International Development Centre of Japan (JICA) upon a request by the Vietnamese government (JICA, 2010a). The overall vision is now for 'Danang to be an internationally competitive Environmental City beyond being pollution-free' (JICA, 2010a, pp. 5–1), and it ensures broader environmental sustainability by responding to climate change, improving the city's preparedness for natural disasters and placing stronger emphasis on the preservation of ecosystems and cultural assets. The DaCRISS promotes developing a compact urban area with mixed land use and emphasises the vital role of urban design and a landscape with natural and cultural elements. The strategy influenced the adjustment of the Urban Masterplan between 2009 and 2013 (see Figure 24).

[19] Vetiver grass is a perennial tussock grass from Asia which is used as a low-cost, effective means of soil and water conservation and land stabilisation (Dalton et al., 1996)

7.3.4 Green Growth Strategy Da Nang

Vietnam has adopted a national Green Growth Strategy (7.2.3) in which major cities are required to localise the initiatives. Da Nang City requested that UN-Habitat and the Global Green Growth Institute (GGGI) develop a localised strategy in 2014. Based on an overview of the local conditions and multi-sectoral stakeholder workshops, the strategy concretised goals for collecting, treating and recycling waste and wastewater as well as for infrastructure and urban development. As a result, key strategic initiatives include 1) sustainable material management, 2) green and public transportation, 3) green industrialisation, 4) integrated water resource management and 5) green agricultural villages linked with green production and ecotourism.

In terms of green space development, the strategy encourages further planting of trees and better protection for existing trees along the coast, riverbanks and natural areas. The rate of agricultural land turnover designated in the Urban Masterplan is criticised as increasing the risk of urban flooding and limiting job opportunities. Denser urban development and better urban sprawl restrictions are recommended, particularly in areas prone to flooding. The strategy is further integrating the planning principles of landscape urbanism into existing architecture regulations to ensure the 'protection and utilisation of green space for landscape improvement, carbon absorption, and the mitigation of the urban heat island effect' (Da Nang, 2014, p. 35). Initiatives such as the Women's Association, Youth Association, Farmer Association, Veterans' Association and Labour Association are identified as potential means to mobilise civil society to create and maintain urban green spaces (p. 33).

Recommended national goals include sustainable but competitive organic agriculture, fostering agricultural tourism, and strengthening urban-rural links and local value chains for supplying the growing market of Da Nang with high-quality organic produce from the region (p.39 and 112). Potential business models with regular delivery of customised packages to urban consumers and institutions such as schools are described (p. 113-115).

Similar to the national strategy, a connection between urban green space development and agricultural production is not laid out.

7.3.5 Local initiatives for food security in Da Nang

It has been reported that several sub-projects progressively implement the content of Vietnam's food security strategy (7.2.4). Several provinces and cities have adopted associated action plans for local agricultural restructuring (Yen et al., 2017, p. 46). It can be assumed that the National Food Security Strategy played a role in updating the Masterplan between 2009 and 2013, which led to the preservation of large agricultural areas against former plans of a total land turnover (see Figure 24).

In 2020, per recommendations by the Department of Agriculture and Rural Development and the international NGO Rikolto, Da Nang announced its intention to become a '*Food Smart City'.* The 5-year collaboration started in 2017 and is part of an initiative of Rikolto in cooperation with the RUAF Foundation. The same initiative has been adopted by the cities of Ghent (Belgium), Solo (Indonesia), Quito (Ecuador), Tegucigalpa (Honduras) and Arusha (Tanzania; (Rikolto, 2020). The overall vision is to improve access to sufficient, nutritious and affordable food for urban and rural residents and to increase smallholder farmers' participation in safe food value chains. The strategy also addresses the need to protect biodiversity, minimise the cities' ecological 'foodprint' (see 2.3.2) and strengthen interregional and urban-rural links (Rikolto, 2019).

By 2019, the project delivered numerous recommendations, including establishing traceability systems of value chains for vegetables, seafood and pork. Improving access to 'safe vegetables' is encouraged by strengthening direct supply of vegetables to restaurants, preferential sourcing for supermarkets to opt for local produce, expanding vegetable production within the city region and implementing *'multi-use urban green-belts'.* Moreover, the strategy recommends implementing regulations and incentives for recovering nutrients and irrigation from organic wastes and wastewater (Rikolto, 2019).

7.4 Implementation, urban transformation and green space development

The following sub-sections provide a brief description of how urban transformation processes are implemented, focussing on agriculture and green space development. The description is based on literature, observations during field trips and comparisons of goals and existing plans with actual implementations. It is not a prime concern of this work to investigate and review the efficiency of planning processes. Hence, interviews with planning authorities and in-depth review of policies would need to be included in future research. Nonetheless, some of the values and opinions of local experts and authorities gathered during the research process are included here.

7.4.1 Appropriation of land for urban development

Since land was acknowledged as having monetary value through the land law reform of 1993, an active land market has developed, albeit unevenly (World Bank, 2012). The state appropriates land for the purpose of 'national defence or security; socio-economic development for the national or public interest' (Law No. 45/2013/QH13, Article 16). To guide urbanisation, the government has seized vast amounts of agricultural land and attached villages for a complete turnover of structures to build new residential areas as well as industrial zones, such as the High-Tech Park in Hoa Vang of more than 1,000 ha. Farmers receive compensation at a price regulated by the state. Substantial disparities have been observed between actual values and compensation amounts, leading to many complaints (Hansen, 2013, p. 13). Moreover, the issuance of land use rights is prone to corruption (World Bank, 2012, p. iv). In particular, the appropriation of land for economic use has been criticised because it allows the transfer of land use rights from initial holders to private entrepreneurs or other commercial parties, leading to increased land speculation (Hansen, 2013, pp. 16–17). Per the 2013 amendment of the land law, investors need to seek permission to appropriate land at higher levels and are now required to provide a Compensation Assistance and Resettlement Plan and a Livelihood Restoration Plan (Hansen, 2013, p. 35). For investment projects requiring 'relocation of the whole population in the community affecting all livelihood', affected people are 'entitled to compensation, support and resettlement to stabilise their livelihood and production in accordance with the Government's regulations' (Law No. 45/2013/QH13, Article 87). However, farmers lose their occupation and have been reluctant to agree to resettlement offers in high-rise apartments that do not provide opportunities for 'home business' (Hansen, 2013, p. 15).

7.4.2 Characteristics of new residential areas

This background partly explains the dominant settlement type in Vietnam based on shophouses. Newly constructed residential areas are several times as dense as former village structures and mostly consist of long rows of shophouses with small porches. According to decision 47/2012/QĐ-UBND for architectural management of works in Cam Le District (Hoa Xuan ward), the construction boundary of *'houses divided into plots'* must be 1.2 m from the 'red line' demarcating the boundary of middle-sized roads (road-bed cross-section ≤ 7.5 m), 1.5 m from larger roads (road-bed cross-section ≥ 10.5 m; see Figure 27). Houses can have up to five floors. In Da Nang, there are a few blocks with a different layout, with villa-style buildings equipped with gardens having their own regulations.

Additional analysis and discussion between a remote sensing expert from the University of Tübingen and experts in urban planning in Vietnam from BTU Cottbus revealed that the general proportion of plots consists of about 35% roads, 60% buildings and 5% parks.

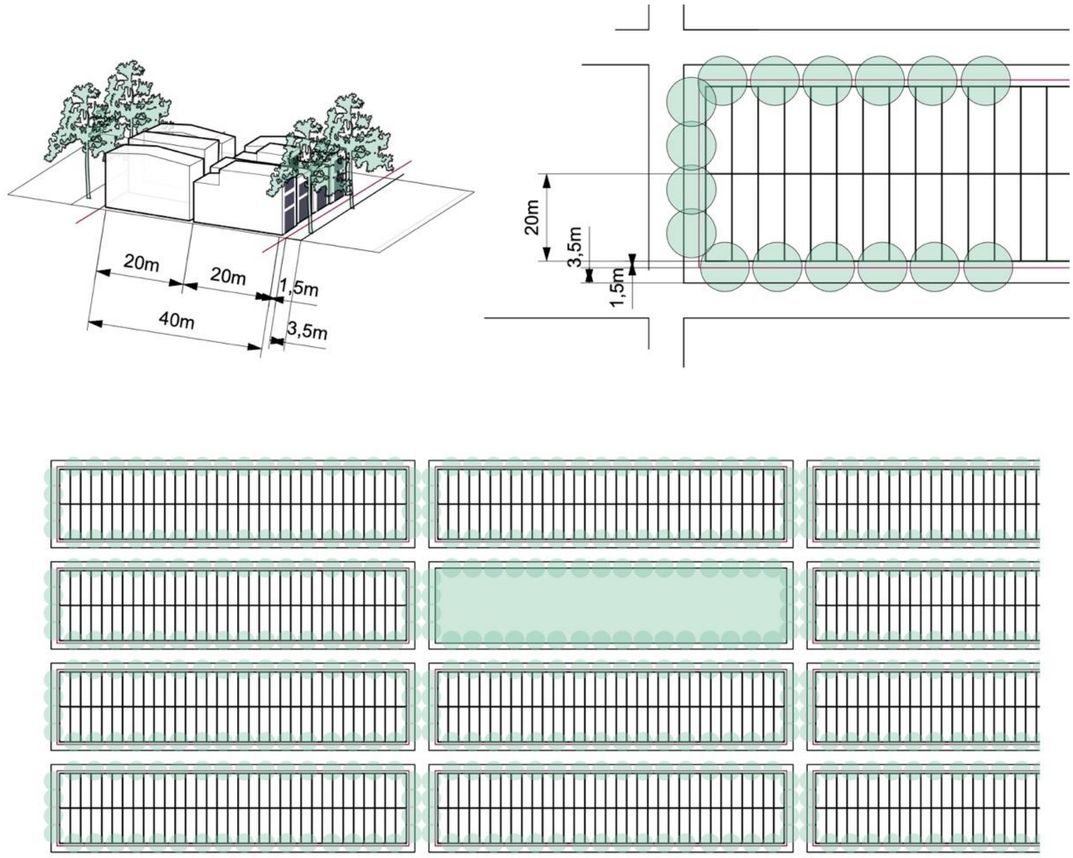


Figure 27 Average proportions of new settlements

7.4.3 Observations on urban transformation and formal green space development

In the following paragraphs, concrete urban transformation processes are described through the urban extension area in Cam Le District, Hoa Xuan Ward, where the Urban Masterplan designated implementation of large connected green spaces (see Figure 25 and Figure 26). To examine urban transformation processes in Da Nang, the geodatabase of the Land Use Plan was adapted in 2020 after processing available aerial images from 2019 from Esri World Imagery. Impressions and spatial references were collected during a field trip in July 2018.

A walk-through of Cam Le District in the area located at the bifurcation of the Cam Le and Cai Rivers in 2018 served to better understand the speed and extent of urban transformation. At the time, only a few villages remained, though villages had formerly covered the whole area. Remnant village structures were characterised by large gardens, acres, banana groves, wetlands and ponds. The settlements and vegetation were progressively deconstructed, and sand was brought to increase the terrain as a countermeasure to rising sea levels due to climate change. This pressing need to change the terrain had led to a 'tabula rasa' approach in which no single grown structure is preserved.

While the Urban Masterplan does not determine the actual allocation of spaces but rather indicates a vision, it is still valuable to compare it to processed land use in 2019. While other parts of Da Nang that urbanised earlier include few to no green spaces (besides beaches), the commitment to a much better green space supply in newly transforming areas is apparent. Some entire blocks have been 'carved out' of residential structures and designated as public parks (see Figure 30, Figure 27). These are equipped with a range of amenities such as benches and sport courts and mostly consist of ornamental plants and lawns with bordering shading trees. During the site visit, the parks were not frequented by residents, but this might have been due to the hot temperatures at the time of the visit.

Deviating somewhat from the Urban Masterplan vision, the newly developed parks do not resemble a network. Existing green spaces consist of the following: greened traffic islands, embankments characterised by patterns of wild vegetation and agricultural elements, accessed mainly by footpaths.

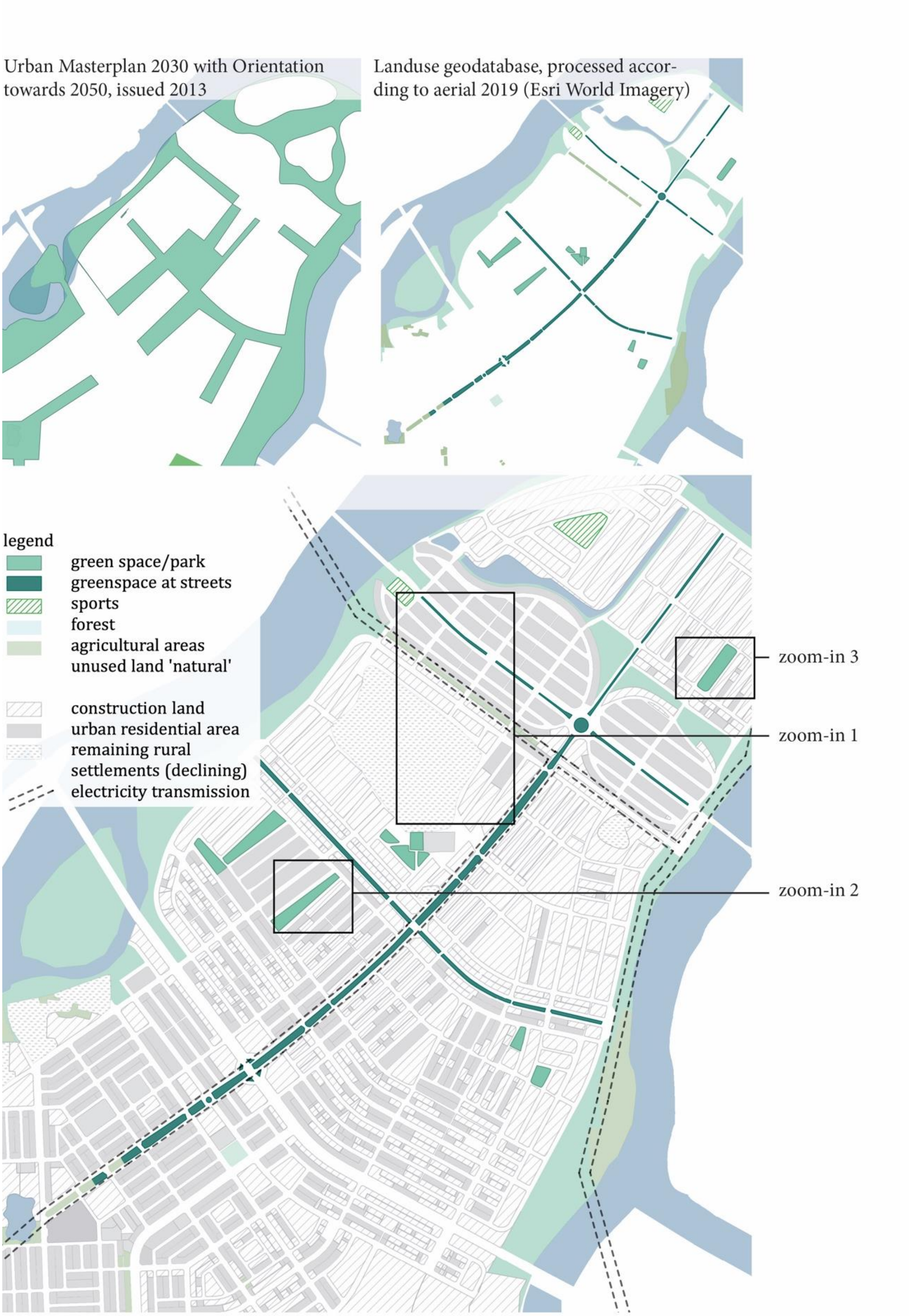


Figure 28 Zoom-in to urban transformation in Cam Le District

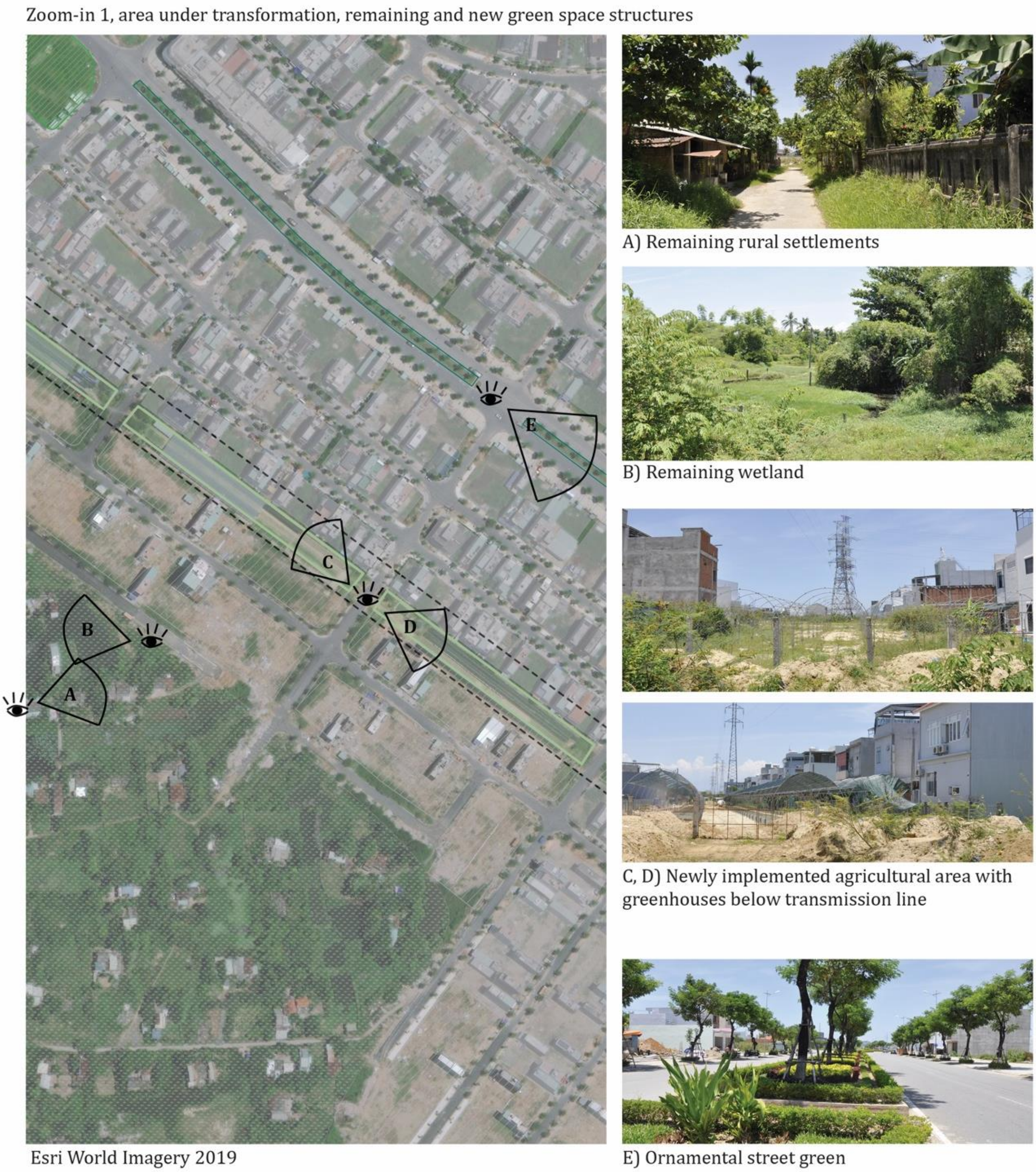


Figure 29 Aerial images and references of urban transformation in Cam Le District

Zoom-in 2, newly implemented greenspaces in urban extension area

Esri World Imagery 2019

A,B) Newly planned park

C) Vegetable patch on vacant lot

Zoom-in 3, newly implemented greenspaces in urban extension area

Esri World Imagery 2019

A,B) Newly planned park

Figure 30 Newly constructed park in urban extension area in Cam Le District

7.4.4 Informal green space development and urban agriculture

Field trips confirmed that Da Nang is characterised by a rich culture of urban agriculture that is practiced by individual civil actors as well as a number of cooperatives. In light of rapid urbanisation and land appropriation, many of the residents engaging to urban agriculture were likely farmers before urbanisation.

The recurrent use of porches or vacant lots to establish small vegetable patches stands out in older parts of the city and in newly developed settlements. Productive units are often equipped with small pergolas, which also function as trellises for climbing plants (see Figure 31). In some cases, these shading constructions are made in a way and from material that creates a rather unappealing appearance (see Figure 31, example E). Presumably, this type of construction does not contribute to the image of urban agriculture as a potentially valid and enriching green space typology.

At the same time, some other manifestations of urban agriculture provide maintenance for the public space. This observation was made repeatedly at the Cam Le River opposite the new development area, which had been a focus in 'Rapid Planning' as part of the so-called entry project. Through a series of stakeholder meetings and observations since 2015, it became clear that the city had difficulties maintaining the recently developed green space at this section of the riverbank (Storch et al., 2018). Ruderal vegetation has grown over the pavement, newly planted trees have dried out and residential garbage has started to pile up. There were repeated cases of residents claiming the unkempt land across from their property to implement small vegetable gardens. Some also repaired the pavement stones and have been taking care of street trees (see Figure 32).

While systematic interviews regarding the image of urban agriculture were not carried out within this study, there often seemed to be some hesitancy whenever the topic was discussed with local experts. The catalogue of green space elements foreseen by the city does not include any type of productive elements, such as community gardens, allotments or commons in the form of orchards. However, one agricultural element seems to be purposely and formally integrated into the layout: greenhouses located below power transition networks. This space is difficult to utilise otherwise (see Figure 29, example C and D).

A) Crop plants at residential wall

B) Vegetable patch at vacant lot

C) Vegetable patch at vacant lot

D) Vegetable patch at vacant lot

E) Larger patch of which the appearance could be improved from an aesthetic point of view

Figure 31 Appearance of urban agriculture in newly constructed urban extension area Cam Le District

A) Poorly maintained greenspace

B) Vegetable garden with public greenspace maintained by resident

C) Villa belonging to the vegetable garden

D) Close-up vegetable garden

Figure 32 Green space maintenance by residents of Cam Le

7.5 Summary and conclusion

7.5.1 Overall challenges and goals

Overall, Vietnam is experiencing continuous economic growth and improved living conditions along with trade liberalisation and modernisation. To ensure continuous rapid growth, the country intends to increasingly move towards sustainable development by implementing social equality reforms and environmental protections; this is reflected in the commitment to the internationally declared SDGs, the New Urban Agenda and all major planning frameworks at the national and local levels. Climate-change-related risks and the rise of seawater levels are seen in the national SEDP as some of the most pressing issues requiring urban development with 'comprehensive, modern and environment-friendly infrastructure'. Expanding green spaces are seen as a central aspect of 'green growth' (see 7.2).

At the local level, Da Nang is a national centre for newly developing industries, transportation and telecommunication. Da Nang has adopted the Environmental City concept as the main strategy for upcoming development. The vision includes ensuring broader environmental sustainability by preserving ecosystems and cultural assets 'where people live in harmony with nature' (7.3.3). All major planning frameworks (SEDP, Urban Masterplan, Environmental City Plan) address metabolic processes, related infrastructures and agriculture to better collect, separate, treat and utilise solid wastes and wastewater for more sustainable urban development.

Da Nang is facing rapid urbanisation, which must be steered carefully to respect a distinctive topography in which only the low-lying plains at the estuary are suitable for urban development and agricultural use. The city is dedicated to carefully balancing between these two land uses and to 'calculating tightly' when turning over agricultural land (7.3.2.2), as per the National Food Security Strategy (7.2.4).

The local Green Growth Strategy and current participation in the Smart Food City programme represent more informal planning frameworks with contributions from international experts. Both strategies reflect overarching goals and add more concrete ideas and suggestions.

The following diagram depicts the major goals expressed in the different planning frameworks at the national and local levels.

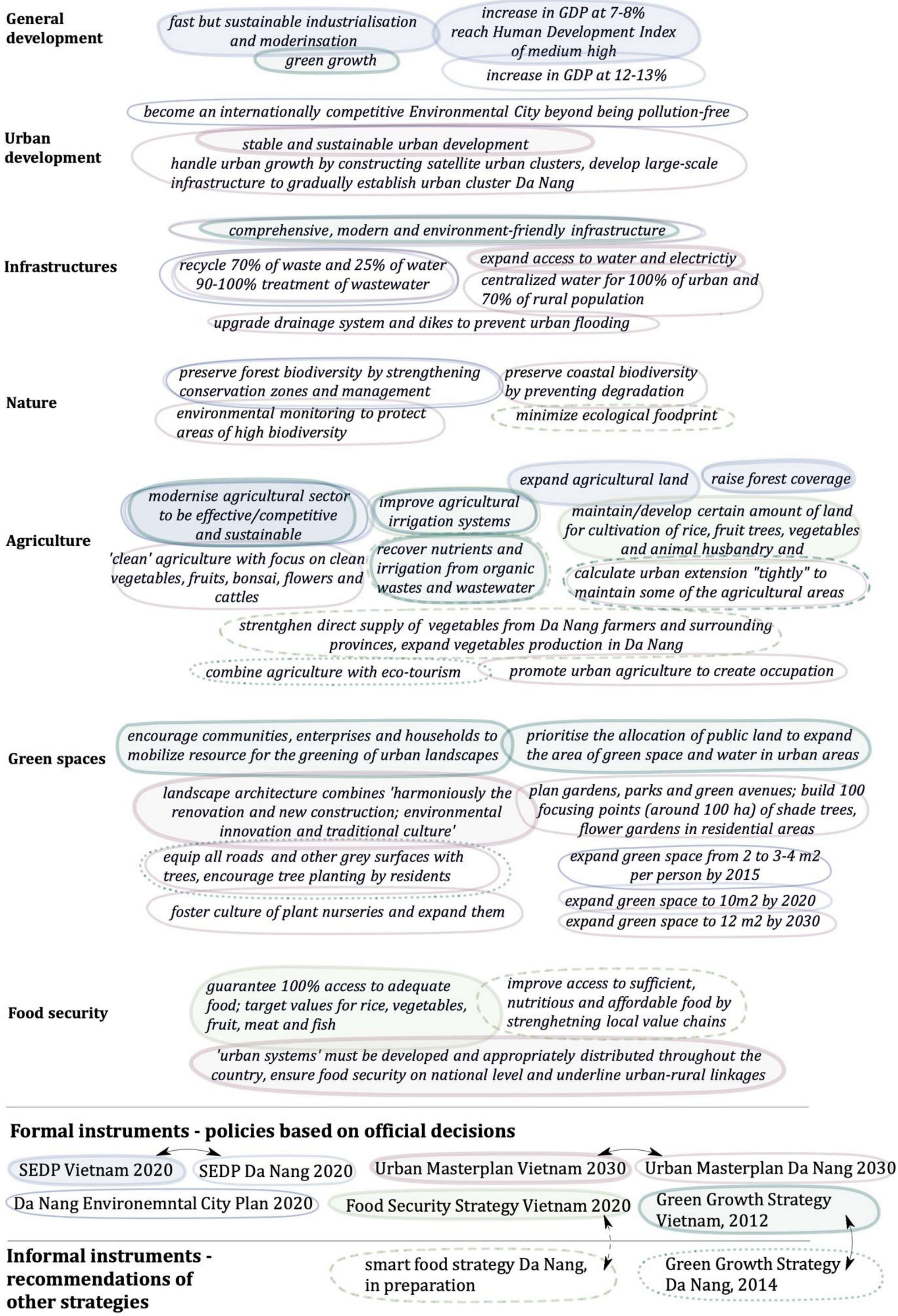


Figure 33 goal cloud for potential PGI development

7.5.2 Urban development is ahead of demand

Based on field trips, aerial image interpretations, opinions expressed by local authorities and the literature, the extent of designated urban extension areas is enormous and has been developed 'ahead of demand', resulting in 'small-scale, fragmented urban expansion' (Do et al., 2018, pp. 2–3) and the striking prevalence of construction land/vacant lots (see Figure 34). The city of Da Nang has identified this inadequacy. During a 'Rapid Planning' scenario workshop organised by TU Berlin, Bui Huy Tri, a representative of the Urban Development Division of the Department of Construction (DOC), stated that while population growth is doubling, the size of the urban area expanding is tripling (Bui Huy Tri, 2018). Urban development based on single-family row-houses is perceived as over-exploiting land and limiting green and public land (Do et al., 2018, p. 10). Fragmented urban expansion thus leads to inconveniences for new residents.

> In rural areas, many inhabitants are dependent on farming and self-supply. Living in urban areas without access to agricultural land is not suitable for them. The atmosphere and lifestyle in the villages used to be very peaceful but is now deteriorating. (Bui Huy Tri, 2018 stated 27th of June 2018).

Bui Huy Tri criticised the lack of regulations imposed on investors turning over land, which has harmed the development of green infrastructure and social infrastructure (Bui Huy Tri, 2018). According to Bui Huy Tri, Da Nang needs to reorientate towards more sustainable development. Low buildings should be limited and building density should be increased to support the integration of green infrastructure and protect the environment. Reorientation towards less land consumption has already taken place as a previous version of the Urban Master plan from 2009 called for almost complete development of the agricultural areas, which was changed with the 2013 revision (see Figure 24).

Figure 34 Aerial of urban extension area

7.5.3 Conceptualisation of green spaces

Theoretically, green space development is highly valued in Vietnam given that all overarching planning frameworks endorse urban green and landscape architecture. The focus of these frameworks lies on recreational aspects and expanding the provision of green space per person, which is estimated as having been around 5 m^2 per person in 2010. About a quarter of this green space consists of treetops of street trees and trees at public institutions, and less than 10% consists of actual public parks or playgrounds. Most of the calculated green spaces (almost 60%) consist of private gardens (see 7.3.2.4). The concept of green infrastructure planning has not been applied. Thus, the availability and accessibility of public green spaces are limited. The map of the Urban Masterplan clarifies that the large residential urban extension areas are supposed to be equipped with more adequate, connected green space systems (see Figure 25).

However, due to speculation, the land is over-exploited, which hinders the Urban Masterplan's vision of connected urban green spaces (see 7.5.1). Dedicating entire blocks to public parks is a major achievement and improvement compared to former urban development, which resulted in an almost total lack of green spaces in Da Nang's urban core. However, the functional and physical connectivity of newly planned structures is still limited (see 7.4.1).

Regarding the quality of green spaces, it seems that their purpose is narrowed to recreation. The neat plant arrangements of the designated green spaces in parks and green traffic islands are evidence of intensive care and give the impression of low naturalness (see 7.4.1). In contrast, a key principle of green infrastructure is multifunctionality, or uniting different functions and purposes such as the recreational needs of urban residents, habitat connectivity for wildlife, cycling and providing urban resources. At its best, a strategically planned green infrastructure acts as a 'natural life support system' (Benedict and McMahon, 2006, p. 1) connecting urban and natural systems (see 3.5).

Many pressing challenges resulting from an imbalance between urban and natural systems are addressed in existing planning frameworks, but the link to the potential role of green infrastructure or urban agriculture is not acknowledged. For example, flood prevention is a major issue, with measures in place to regulate rainwater as quickly as possible outside the urban system. However, the potential of urban green spaces – or blue-green infrastructure (see 3.5.2) – integrated into residential structures to redirect surplus rainwater and provide retention space is disregarded (see 7.3.2.5).

Until Da Nang's recent participation in the Smart Food City programme (7.3.5), food security was discussed only at the national level, though mounting evidence has pointed towards the importance of city region food systems (4.4.2). As food systems are major drivers of global change (see 2.3.2), food system planning should consider impacts on biodiversity and climate change and bundle efforts towards maximum efficiency regarding the use of resources, including land, water and energy. The Vietnamese food security strategy aims at developing 'food circulation systems' to guarantee access to adequate food for 100% of the population. It defines minimum amounts of land dedicated to producing certain food groups, including rice and vegetables. While rice as a staple crop is bound to large-scale production fields and can be stored and transported easily, it seems appropriate to endorse the production of vegetables within the realm of urban regions as this would allow more resource-efficient management and tackle current food safety uncertainties (see 8.1.1.2) by strengthening relationships between consumers and producers within the region.

Last but not least, urban agriculture as part of the everyday life of many residents is entirely dismissed in urban planning (see 7.4.4). The current generation populating urbanising areas is still familiar with the culture of food growing and preparation. The apparent enthusiasm to grow food and tend to green spaces in the immediate residential and living environment is clearly an overlooked asset. Encouraging this movement and operationalising certain identified typologies of urban agriculture could be a remedy to current challenges. In the short term, urban agriculture is a useful intermediate use for the abundance of vacant lots and can even contribute to the maintenance of public green spaces (7.4.4). In the long term, urban agriculture could play a key role in designing urban neighbourhoods with an optimised urban metabolism (see 3.1) in which wastewater and solid wastes are better utilised, thereby tightening resource loops; this matches the goal of the infrastructure development of Da Nang (7.3.2.6). The formalisation of urban agriculture could also improve aesthetic quality and overall usability to add to the local atmosphere.

Strengthening these types of social movements would require more active participation of local stakeholders into planning processes, which has been declared a requirement for sustainable development by the international community and which is currently identified as a shortcoming in Vietnam (7.2.1.3).

8 ASSESSMENT OF SPATIAL AND SYSTEMIC DIMENSIONS OF URBAN AGRICULTURE

This chapter explores the key research question of how urban agriculture can be assessed spatially and systemically through the case study of Da Nang. The objective is to capture the characteristics of urban agriculture, collect better data regarding urban agriculture's spatial extent, and thus gain a better understanding of urban agriculture's role in the city's urban food system in terms of contributing to the food supply.

This case study is based on the author's work as a research assistant in the 'Rapid Planning' project (see final report - Kasper et al., 2019; and deliverable report D-3.4 Lindschulte et al., 2019a) and was further consolidated in this thesis. Cooperation with local experts significantly contributed to the author's understanding of urban agriculture and urban planning processes and facilitated access to relevant official reports, planning documents and extracts from the land use information system. Moreover, data and information was compiled by the research consortium, which confirmed the shortcomings of remote sensing for small-scale urban agriculture.

The first subchapter describes existing knowledge and data gaps regarding urban agriculture in Da Nang (8.1). After this, a methodology for better assessing urban agriculture's spatial and systemic dimensions is proposed (8.2). The steps comprise conflating different data and information sources and refining the patchwork of information through individual data collection. A strongly interlinked workflow[20] is thus developed based on identifying distinctive features of urban agriculture; collecting references for aerial picture interpretation; processing land use geodata; and defining, quantifying and documenting a set of characteristic typologies (8.3). These steps produce a more consolidated overview of urban agriculture's contribution to Da Nang's urban food system (8.4). A summary and conclusion are then presented (8.5).

8.1 Existing knowledge of urban agriculture in Da Nang

This section outlines existing knowledge of urban agriculture in Da Nang and its role as part of the urban food system in terms of supporting the accessibility of fresh produce and influencing the 'food environment' and diet choices.

8.1.1 Characteristics of urban agriculture in Da Nang

8.1.1.1 Prevalence of urban agriculture

Da Nang's extensive territory still contains large areas of peri-urban agriculture. The majority of crop production is characterised by paddy fields, a cultivation method that is particularly suitable for the low-lying plains of Da Nang. However, the rice produced in Da Nang is considered low quality and is processed into other products such as rice noodles (bilateral meeting with DARD, 17.3.2015). Local farmers aim to improve rice quality and raise the share of organic rice to supply the local market (expressed during scenario workshop 27.6.2018). Apart from rice, only minor amounts of locally produced food are exported, and it is assumed that except for fish and rice, all products – especially fresh vegetables and fruit – are consumed locally (Schmidt et al., 2016 Interviews with the Farmers Union in Hoa Vang).

Existing studies on a global scale find a relatively high occurrence of intra-urban agriculture in Vietnam. Based on data from 1998, almost 65% of urban residents participate in crop growing – the highest share among the 15 developing countries observed (Zezza and Tasciotti, 2010, p. 268).

The prevalence of urban agriculture is reflective of Da Nang (Kohlbacher, 2015; Quan et al., 2013). Rapid appraisal of urban agriculture is believed to be driven by rapid urbanisation and the loss of agricultural land. In Da Nang, urban development dedicates large areas for future construction and thus has quickly transformed former agricultural land (Quan et al., 2013, p. 7). Presumably, former residents moving into newly built settlements keep their farming habits by growing edible plants on porches, rooftops, balconies, public land or vacant lots. Data on existing urban agriculture is scarce and inadequate.

A clear trend of a rapid reduction is apparent in agricultural statistics. According to the statistics for 'Planted area of crops', distinguished into annual (food and industrial) and perennial (fruit and industrial) crops, the total size of agricultural land shrunk by approximately 35% from 2007 to 2015, going from 13,319 ha to 8,598 ha (Da Nang statistics office, 2016 section 126). Furthermore, the number of farms in

[20] Workflow is here established as the term for a series of working steps of field mappings, aerial picture interpretation and geodata processing

Da Nang is decreasing rapidly (Da Nang statistics office, 2016, p. section 124). The Urban Masterplan 2030 predicts that merely 3,000 ha in the Ho Vang District will be classified as 'agriculture and villages', while another 1,300 ha will lie in areas roughly categorised as green spaces in 2030. However, the purpose of the Urban Masterplan is to illustrate a vision and development direction, and it does not guarantee clear-cut agricultural spaces in the future. Though former version of the plan recommending the total erasure of agricultural land has been revised, the current plan nevertheless indicates that agriculture will be concentrated in the fertile lowlands on the outskirts of the city (see 7.3.2 and Figure 24).

8.1.1.2 'Safe vegetables' as a boost for urban agriculture

Following repeated episodes of unsafe food in Vietnam, food safety is a growing concern, particularly regarding toxic pesticide residues in vegetables, motivating the production of so-called 'safe vegetables' in urban areas.

The topic of food safety frequently appears in newspapers and television and is subject to policy discussions. Food safety is perceived as one of the most pressing issues for Vietnamese citizens and is more important than education, health care or governance (World Bank, 2017, pp. 15–16).

Regarding chemical hazards, the use of pesticides and antimicrobials is relatively high in Vietnam, often leading to residues in the produce. Overuse of pesticides has been recorded to be 10–17 times higher than the Ministry of Agriculture and Rural development's recommendation (Truong et al., 2017, pp. 120–121). A report of the Ministry of Agriculture and Rural Development (MARD) found that 3%–6% of vegetable samples taken in 2012 and 2014 exceeded health standards (World Bank, 2017, p. 52). Moreover, soils can be contaminated with dioxin, as is the case at Da Nang Airport (see 6.3.1.2). Beyond the process of growing crops, chemical hazards can also arise during harvesting, prolonged storage and processing (e.g., colouring to create a riper appearance or disinfection). Regarding biological hazards (e.g., parasites, fungi, bacteria, viruses and prions), specific parasites were found to contaminate 15% of tested vegetables (World Bank, 2017, p. 50).

There were 373 recorded outbreaks of foodborne diseases in 2014 and 2015, with over 10,000 cases and 66 deaths in Vietnam. It is assumed that only a small percentage of these outbreaks are documented (World Bank, 2017, pp. 15–16). Some links between food safety and health cannot be directly documented. For instance, it cannot be traced to what extent the rate of cancer is caused by unsafe food, which means that the negative effects of unsafe food might be more severe than realised (Truong et al., 2017, p. 120).

To tackle these issues, the government has drafted food safety legislation and introduced third-party certification for compliance with Vietnamese Good Agricultural Practices (VietGAP), which is the basic Good Agricultural Practices (GAP) with simplified requirements. Another initiative builds on community-based certification, with monitoring, inspection and certification carried out by the local community. By 2017, certified food still had a low share of 10% in Vietnam's total market (World Bank, 2017, p. 15).

During the research in Da Nang, it became apparent that 'safe vegetables' (in Vietnamese 'rau an toàn') has become a fixed term comparable to 'organic' in Western cultures. However, 'safe' does not mean the total absence of pesticides but rather is a production mode in which pesticide residues, nitrate content, heavy metal content and pathogens are below the GAP levels (Simmons and Scott, 2007).

A recent study conducted among 30 consumers in Hue, a neighbouring city of Da Nang, found that 96% were interested or very interested in and had a high demand for safe vegetables. Half of them found that these were expensive but not too expensive. However, the level of safety was not judged based on certificates only but also by observation and the smell of produce as well as trust level towards the retail facility (Truong et al., 2017, pp. 123–124).

Concerned consumers' demand for safe vegetables has created new market opportunities, and the number of producers with safe vegetable certifications has been increasing all over Vietnam since the mid-2000s. Farmers in the vicinity of urban areas are increasingly transitioning from growing rice to higher-value crops such as vegetables and fruit (Simmons and Scott, 2007). This transition from rice to vegetables is also documented in Da Nang (Quan et al., 2013, p. 7). Urban farmers' proximity to consumers benefits the establishment of value chains for safe vegetables and builds trust among consumers. Urban farmers can advertise the freshness of their produce and reduce post-harvest processing due to short transportation routes.

Da Nang has at least seven safe vegetable cooperatives. One cooperative is situated on the Cam Le River on an island with regular flooding and a productive area of 5 ha. In 2016, the Agricultural Division of Hoa Vang People's Committee reported six active cooperatives with a total production area of 75.2 ha and another three planned with a total production size of 11.5 ha. The Tuy Loan Safe Vegetable Cooperative in

Hoa Phong (5 ha) and the La Huong Vegetables Cooperative (7 ha) are among the larger cooperatives (Quan et al., 2013, pp. 18–19; Schmidt et al., 2016).

Da Nang has also increased the monitoring of incoming products from other regions. Since 2016, the origin of all imported vegetables must be declared to the appropriate ministry. In 2017, the city signed agreements with at least three provinces to develop safe food chains (Rikolto, 2020).

8.1.2 Urban agriculture as part of Da Nang's urban food system

The following sub-section outlines how urban agriculture is part of the Da Nang's urban food system. The urban food system approach analyses the process components which ultimately determine food provision in the city (see Figure 35 and Chapter 3.2.2). Here, urban agriculture is seen as a component of the production process.

Da Nang is connected to the global food system as the production, processing and transportation of food that is ultimately consumed in Da Nang can stem from many places around the world. However, many of Da Nang's citizens are engaged in growing vegetables and fruits, fostering a rich culture of urban agriculture and local markets that is reinforced by previous food safety issues and rural-urban migration spurred by rapid growth. Thus, urban agriculture drives the accessibility of fresh produce and majorly influences the 'food environment' and diet choices. Conceptualising urban agriculture as part of the urban food system corresponds to the urban metabolism perspective and supports tightening the resource loops of water and nutrients.

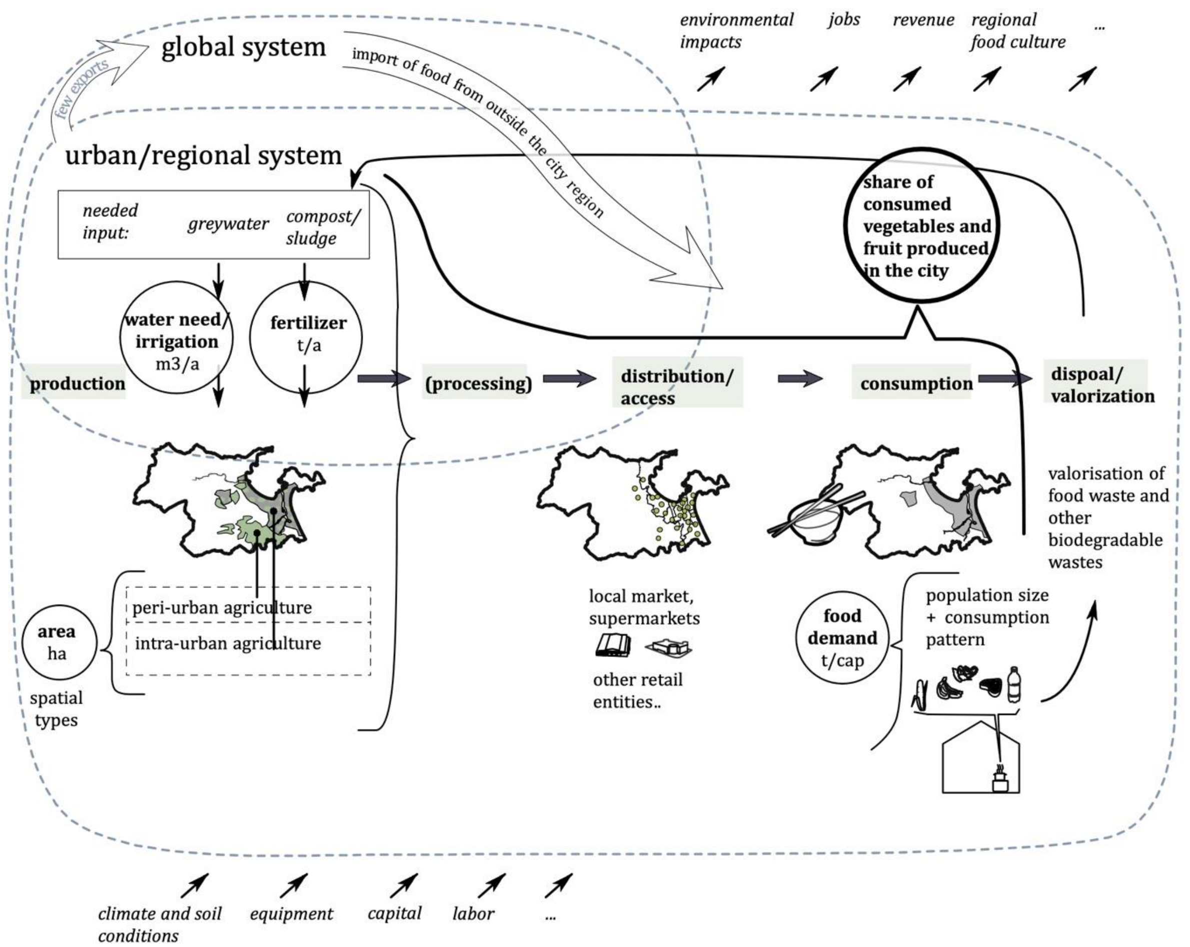


Figure 35 Comprehensive diagram of Da Nang's urban food system components. Further developed on the basis of the graphic in Kasper et al. 2017, Figure 2

8.1.2.1 Urban agriculture and component processing

As described in Chapter 3.2.2.2, the way food is processed and consumed is increasingly understood as key to healthy and sustainable diets (Monteiro et al., 2012). Vietnamese cuisine has a high share of raw or slightly cooked and fresh ingredients. As these food items perish quickly and cooling fresh produce over long distances is energy-intensive, agricultural areas within the large territory of Da Nang offer a valuable opportunity to supply the local market. Merely 2% of agricultural areas are currently dedicated to vegetable production, according to existing statistics (see Table 11). It can be assumed that the share is higher in reality because secondary vegetable gardens integrated into the urban structure are not fully covered in the statistics (see 8.2.5). Da Nang's Green Growth Strategy (see 7.3.4) identified a clear trend towards producing higher added value due to the loss of agricultural land. The strategy recommends further improving local goods' quality to supply the local market with high-quality products (UN Habitat et al., 2014, p. 56).

8.1.2.2 Urban agriculture and component distribution/access

A high share of urban agriculture and close proximity between producers and consumers entails the accrual of fewer 'food miles'. Chapter 3.2.2.3 described how food distribution systems can substantially influence the energy balance of cities and the level of greenhouse gas emissions. A study in Korea found that in locations with a temperate climate requiring cooling of food and year-round production conditions, significant amounts of CO_2 emissions could be cut through more regional distribution systems (Lee et al., 2015). Moreover, creating strong food environments is a key issue of urban food system planning to provide healthy and sustainable food choices (Global Panel on Agriculture and Food Systems for Nutrition, 2016).

It is estimated that 90% of vegetables circulating in Da Nang are distributed through two large wholesale markets, Metro Market and Chợ Đầu Mối Hòa Cường Market in Cam Le, which transfer food to other retail markets or end consumers (bilateral meeting with DARD, 17.3.2015). Further distribution happens at 57 traditional local markets and an increasing number of large European, US, and Japanese retailers seeking to enter the Southeast Asian markets (Vietnam Supply Chain, 2013, p. 23). In 2016, there were 64 supermarkets operated by large grocery retailers (Interview with DoIT, see Schmidt et al., 2016) (Than, 2016).

Local markets are assumed to be major transhipment sites for produce yielded from local urban agriculture as they are operated by individual vendors selling to end consumers (Quan et al., 2013, p. 19). The Vietnamese government aims to invest in improving these traditional wet markets to support small traders and sustain local value chains (Vietnam Supply Chain, 2013, p. 23). Moreover, mobile street vendors offer fresh produce or ready-to-eat snacks (e.g., grilled maize) in populated areas and at the entrances of larger building complexes such as hospitals, malls or schools. Street vendors with fixed locations are registered through the Wards of the People's Committee.

Direct sales from producers to consumers is a growing trend due to food safety concerns and is also endorsed by local planning frameworks such as the Da Nang Green Growth Strategy to connect recreation, eco-tourism and urban agriculture.

8.1.2.3 Urban agriculture and the component consumption

It is of key research interest to understand the extent to which urban agriculture contributes to urban residents' food supply. According to a 2011 study conducted at Hong Duc University, urban agriculture meets 55% of vegetable and fruit demand in the capital Hanoi (< 6 million citizens), 18% in Ho Chi Minh City (< 8 million citizens), 65% in Hai Phing (ca. 800,000 citizens) and 30% in Da Nang (ca. 1 million citizens; (Le, 2011; cited in Quan et al., 2013, p. 7). The local authority DARD estimates that 35% of vegetables and fruit consumed are produced within the city (Bilateral meeting with DARD, 17.3.2015).

General trends in Vietnamese consumption patterns have already been thematised in Chapter 6.3.1.2. Rising living standards and higher incomes have led to a change in diets, with notably increased meat intake. Meat, fruit and vegetable consumption are lower in low-income households and are replaced by higher rice intake. It can be assumed that if fruit and vegetables were more affordable and accessible, their consumption would be higher in low-income households.

To fully assess the extent of urban agriculture's contribution to the urban food supply, it is necessary to interrogate typical consumption patterns. To date, there is no data about food consumption in Da Nang, but there are three major sources of food consumption data at the national level – the national statistical yearbook, FAO statistics and the National Food Security Strategy. Each of these offers distinct information.

The national statistical yearbook includes a section on average per capita monthly consumption of several main goods. These statistics comprise differentiated datasets for the urban and rural populations as well as differentiation according to household income and time series to highlight specific trends. The second major source of information is the food balance sheets of the FAO. This dataset quantifies food items potentially available for human consumption; it is calculated based on national production data added to total imported quantities and also considers quantities exported, fed to livestock and lost during storage and transportation. Another viable orientation in assuming average consumption pattern in Vietnam can be drawn from the Vietnamese food security strategy, which aims to provide set quantities of defined food groups (see 7.2.4).

Over the course of the 'Rapid Planning' project, a material flow analysis (MFA[21]) of food from source to sink was completed to evaluate the quality of collected data by integrating and comparing different data sources. By correlating stated food quantities with nutrient supply intake, it was found that the stated quantities of the Vietnamese statistics are far too low and the data inadequate (Franke et al., 2020, pp. 12–13). Regarding the food groups with specific per-person provision target quantities in the Vietnamese food strategy, the values are lower than the FAO's estimated consumption but higher than the Vietnamese statistics.

Actual food consumption quantities are difficult to estimate using data sources. However, the values specified as the target direction at the national level seem most plausible. Since these values describe goals, they are suitable for the calibration and evaluation of urban food systems. They will further be used to determine the degree of food self-sufficiency. Based on the extended MFA cross-checks, the FAO datasets seem plausible regarding the remaining food groups than Vietnamese statistics. Still, trends and different consumption patterns of the social groups reported in the Vietnamese official statistics are analysed and considered in this Chapter.

Table 5 Calculated food consumption in Da Nang, comparison of FAO and national Vietnamese statistics

Food groups	Estimated consumption				Provision goal	
	(FAOSTAT, 2014)		(General Statistics Office in Vietnam, 2016)		Goals Vietnamese food security strategy (see 7.2.4)	
	Da Nang[22] t/year	*per capita kg/day*	Da Nang t/year	*per capita kg/day*	Da Nang t/year	*per capita kg/day*
Rice	193,362	*0.603*	72.647	*0.227*	89,029	*0.273*
Other cereals	19,354	*0.060*	11.751	*0.037*	-	-
Meat	59,622	*0.186*	23.503	*0.073*	40,063	*0.123*
Grease, Oil	4,291	*0.013*	3.205	*0.010*	-	-
Fish, shrimp	59,622	*0.086*	16.025	*0.050*	26,709	*0.082*
Tofu	-	-	4.273	*0.013*	-	-
Sugar, molasses, milk, cake, candy, candied fruits	23,387	*0.073*	6.410	*0.020*	-	-
Fish sauce and dipping sauce	-	-	3.205	*0.010*	-	-
Tea, Coffee	2,679	*0.008*	1.068	*0.003*	-	-
Bean of all kind	6,739	*0.021*	1.068	*0.003*	-	-
Peanut, sesame seed	10,104	*0.03*	1.068	*0.003*	-	-
Vegetable	136,935	*0.427*	21.367	*0.067*	106,835	*0.328*
Starchy roots (Cassava, potatoes, sweet potatoes)	12,980	*0.041*	-	-	-	-
Pulses	1,059	*0.003*	-	-	-	-

[21] For further explanation of MFA, see Box 2)

[22] Multiplied with the number of residents 890,292 in 2014

Spices	2,056	*0.006*	-	-	-	-
Total vegetables group	153,032	*0.477*	-	-	-	-
Fruit	67,404	*0.210*	12.820	*0.040*	44,515	*0.136*
Dairy (milk, butter)	5,065	*0.016*	n/a	*n/a*	-	-

8.1.2.4 Urban agriculture and component disposal/valorisation

The majority of solid waste (75%) generated in Da Nang consists of *'food and garden waste'* (UN Habitat et al., 2014, p. 17). Collecting and treating the increasing amount of waste is a challenge in the rapidly urbanising city. The current collection rate is stated to be 86%, with the remaining waste ending in water bodies. Waste is collected unseparated, and the existing landfill has exceeded its capacity, with resulting leachate issues (DOC, Da Nang, 2015, pp. 50–51).

The city plans to raise the collection rate to 100% in urban areas and to 90% in the more rural Hoa Vang District. More importantly, the city plans to start engaging in at-source waste separation by supplying households with waste containers of different colours (DOC, Da Nang, 2015, pp. 166–171).

Separation at source would enable the valorisation of waste. The large fractions of biodegradable wastes could be used for composting or power generation. The Da Nang Green Growth Strategy recommends implementing composting initiatives to reduce the amount of organic waste from the food and agriculture sector and to replicate the nutrient cycles of the natural ecosystem. In this way, fertilisers can be generated and resources can be re-integrated into the process of cultivating food (UN Habitat et al., 2014, pp. 17–18).

8.1.3 Knowledge and data gaps regarding urban agriculture in Da Nang

The literature review revealed inconsistencies in the documentation of urban agriculture's spatial manifestation in Da Nang in both the agricultural census in the statistical yearbook as well as the land use geodatabase. Remote sensing carried out by 'Rapid Planning' project partners could not capture small-scale intra-urban agriculture.

8.1.3.1 Land use geodata base and agricultural census

The total number of agricultural production areas is inconsistently documented, and existing official reports exclude urban agriculture on 'abandoned land and fallow land' (Kohlbacher, 2015, p. 28). Hence, more in-depth spatial assessments need to be carried out.

Through collaboration with local experts, it was possible to obtain the geodatabase of the land use plan. According to the data, 7,468 ha account for agriculture, with the majority being used for wet rice (3,918 ha), followed by annual crops (2,103 ha), perennial crops (1,131 ha) and aquaculture (316 ha).

These numbers are not entirely compatible with the statistical yearbook, which may include inconsistent datasets. In the first chapter dealing with land use, the total area of 'agricultural production land' is documented as accounting for 6,811 ha (Da Nang statistics office, 2016 section 3). In a different section, the total 'planted areas of crops' is stated to be 9,402 ha, consisting of 8,598 ha of annual and 804 ha of perennial crops. Additional confusion derives from the fact that the listed amounts of annual food crops (5,735 ha), annual industrial[23] crops (1,204 ha) and aquaculture (400 ha) do not add up to the quoted total of 8,598 ha (Da Nang statistics office, 2016 section 126).

The section of the statistical yearbook dealing with land use (Da Nang statistics office, 2016 section 3) includes data on agricultural production land by district. For the dense old urban districts of Son Tra and Hai Chau, some of the areas were partly included in this section but without specifying crop types. Overall, quantities on the district level do not match; this becomes most apparent for Hoa Vang (see Table 6). It is assumed that these inconsistencies derive either from different spatial assessment methodologies (either

[23] Perennial industrial crops include cashews, pepper, tea and coconuts. Annual industrial crops include peanuts, sugar cane and tobacco

geodata-based land use assessment or textual reporting of land sizes from farmers or districts) or from reference to different categories.

Based on this analysis, it can be assumed that the reported production of single crops only refers to production from 'regular' peri-urban agriculture and that other types of urban agriculture more integrated into the city structure are not included.

Table 6 Agricultural production, comparison of agricultural census and land use data

Districts	Statistical yearbook 2015 section p. 245 ff.						Statistical yearbook 2015 section 126 ff., sum of planted areas of crops	Statistical yearbook 2015 section 3	Original GIS land use data, ca. 2015
	Available statistics of selected products, area in ha							Total production area including aquaculture in ha	
	Aqua-culture	Cereals	Sweet potato	Cassava	Peanut	**Sum**			
total	**470**	**5757**	**332**	**171**	**512**	7,242[24]	8,104	6,811	**6,858**
Lien Chieu	60	36	9	-	7	118		203	208
Thanh Khe	-	-	-	-	-	-		5	0,6
Hai Chau	-	-	-	-	-	-		8	0
Son Tra	-	-	-	-	-	-		25	3,5
Ngu Hanh S.	10	277	-	25	97	416		505	482
Cam Le	1	128	-	-	9	139		232	105
Hoa Vang	399	5316	323	146	399	7,261		5,833	6,058

8.1.3.2 Remote sensing: Supervised land-cover classification and Normalised Vegetation Index (NDVI)

The 'Rapid Planning' project included work packages dedicated to collecting information via remote sensing about land use, building types, infrastructure, urban and peri-urban structures, and surface and building materials. The sensing was carried out by the University of Tübingen's Department of Geography.

The University of Tübingen obtained high-resolution Pléiades satellite data for the densely built-up area of Da Nang (resolution of 0.5 meters) and RapidEye scenes (resolution of 5 meters) for more rural areas, both from 2015. The RapidEye data was used for supervised land-cover classification, distinguishing between the water, forest, green land, agriculture, bare soil, urban and road classes (see 4.5.2). Based on ongoing coordination and data exchange, it was determined that the initially identified typologies of urban agriculture ranging from small to medium scale *cannot* be derived by remote sensing and supervised land-cover classification. The typologies were too small and created a heterogeneous structure, which meant that other approaches had to be identified in the research.

Moreover, a Normalised Difference Vegetation Index (NDVI) was derived, distinguishing between no, low, middle, high and very high vegetation (see 4.5.2.3). Based on the detailed Pléiades satellite data, a green cover ratio determining the share of vegetation cover was developed (Braun and Hochschild, 2018).

The work package's focus was to identify urban structure types (USTs) and building types. Classification of characteristic urban structure types and assessment of vegetation cover was later used for a study mapping the level of urban agriculture within the individual types (see 8.2.4).

[24] Not including all crops as data per district is only available for selected crops

8.2 Case study methodology: Assessment of urban agriculture's spatial and systemic dimensions

Understanding urban agriculture as part of a strategically planned green infrastructure requires an assessment of its spatial extent and manifestation in the city, which have not been inventoried so far. Small-scale urban agriculture in particular is not part of the existing statistics or land use geodatabase and could not be captured sufficiently through remote sensing (8.1.3). This lack of data and knowledge required developing an original assessment approach. This chapter discusses the steps taken to deepen understanding of urban agriculture's spatial extent and create a better basis for further planning processes in the sense of a PGI network.

The workflow comprises conflating the existing data and information sources and identifying data gaps as well as potential areas to refine and process existing data. A key process is identifying distinctive features of urban agriculture and defining characteristic typologies (8.2.1). It is then shown, how each of the typologies can be assessed by collecting references in the field, interpreting and tracing aerial imagery from remote sensing and processing existing land use geodata (8.2.2). The generated data is then put into context with the existing census (8.2.3). To assess the urban agriculture entities that are too small to be identified remotely, samples were collected within the framework of a city-wide urban structure type classification (8.2.4). A final step is aligning all the gathered data and information with existing agricultural statistics, which omit most urban agriculture, to create a better understanding of the actual productiveness of the city (8.2.5).

The assessments results in a set of spatialised characteristic typologies that can be considered in urban development and green space planning and a consolidated overview of Da Nang's urban food system.

8.2.1 Urban mappings and initial typologies

To identify the possibilities of urban agriculture and define planning goals for a potential PGI network, it is necessary to capture the typical local features of urban agriculture's evolution as a spatial structure and how it blends into the urban formation. Identifying typical patterns to define typologies is a common approach for holistic assessment and operationalisation of urban agriculture (3.3.4). Distinguishing typologies also allows differentiation of the ways for estimating the total spatial extent of each type.

One way to gain an initial impression of the typical manifestations of urban agriculture is to conduct field trips and mappings. These mappings were prepared by analysing topographic plans and aerial images to cover different morphologies of the city, which in Da Nang are dense urban areas, residential neighbourhoods, riverbanks and the coast. Manifestations of urban agriculture were captured through photographs, marking locations on a map and making notes and sketches. Then, repeated patterns were observed to derive parameters for the typologies.

Ultimately, parameters to classify Da Nang's typologies are oriented to the synthesis of the literature review (see 3.3.4.1 and Figure 7):

- Size (large > 5 ha, medium 0,025–5 ha, small > 0.025 ha),
- Type (primary or secondary agriculture),
- Purpose (subsistence or sale),
- Products (cereals, fruits, and vegetables, animal products) and
- Special features (e.g., temporary or building-related cultivation, geography or specific cultivation system).

The distinction between primary and secondary urban agriculture is based on results from the research project 'Urban Agriculture as an Integrative Factor of Climate-Optimised Urban Development, Casablanca / Morocco' (2005–2013).

> Primary Urban Agriculture is characterised as any and all agricultural units of arable land which are regularly and generally used for agricultural activities within a city region. (…) Secondary Urban Agriculture stands for agricultural activities in areas primarily used for socio-economic purposes other than agriculture. It includes all those activities that are co-existing with or overlaid upon another form of land use. (Giseke et al., 2015b, p. 32).

Primary agriculture is understood as large-scale fields measured by official statistics and located in areas officially designated for agriculture according to land use planning. Secondary agriculture comprises any multifunctional space in which agriculture occurs as an add-on, for example, within residential gardens, parks or rooftop gardens. It is more likely to be integrated within the urban structure and is small-scale.

Six different typologies were identified and progressively assessed.

Typologies assumed to be covered by official statistics (see 8.2.3) are:

- P1) Primary agriculture, 'regular' agriculture, covered by official statistics

Secondary types assessed by geodata processing, aerial picture interpretation, field trips (see 8.2.3) are:

- S1) Plots along rather natural open spaces
- S2) Urban farming plots
- S3) Construction/ fallow land

Assessed based on mappings in correlation with urban structure types (USTs; see 8.2.4)

- S4) Small-scale urban agriculture (residential gardens, small-scale use of public space)

A final distinctive typology that could not be assessed through mappings is:

- the use of S5) Rooftop gardens.

8.2.2 Land use geodata processing

As this work explores PGI as a spatial planning approach, existing land use data was used for assessment as it represents a comprehensive land cover dataset with separated polygons for different land uses (see 4.5.2). Comparison of the land use geodata with findings of initial mappings revealed that some land was not demarcated as 'agricultural area' in the dataset.

Hence, an approach had to be developed through an iterative work process of mappings and geodata processing to better assess these spaces and distinguish between the identified typologies.

The received data represents not the status quo but a plan for the near future, as minor areas were depicted as built up and currently belong to other land use classes such as agriculture. To depict the current status of land use, the geodata's polygons were compared with aerial images and reworked. Moreover, the original database included an 'unknown' class accounting for 2,301 ha which had to be allocated to corresponding classes. The majority of the 'unused' 3,946 ha were allocated to two new classes, namely 'natural unused' areas visibly covered by vegetation and 'construction land' resembling open soils or sparse vegetation located within the territory of newly designated urban extension areas or within urbanised areas. Interpretation of aerial images also revealed large areas of 'mining', where soil is extracted and used for land reclamation and protection in the lowlands and banks.

The aerial images used were the high-resolution Pléiades satellite data for the densely built-up area of Da Nang (resolution of 0.5 meters) and the RapidEye scenes for more rural areas (resolution of 5 meters). Moreover, the state of urban development and areas demarcated as built-up and with other land uses were visibly cross-checked with other up-to-date aerial images at the time of processing in 2018. For further comprehension and verification, the land use data was aligned with the content of the Land Use Plan 2025 (QH-02), which is slightly generalised and depicts areas of land use rather than actual boundaries.

Urban agriculture samples collected during field trips were fed into the geodatabase (see 8.2.3).

Table 7 Processing of GIS data, Da Nang land use data, obtained through cooperation between University of Tübingen (Germany) and Hue University (Vietnam) in 2017

Land use type	Land use data Hue Uni in ha		
	Original ca. 2015	Processed according to aerial 2015	Steps of geodata processing
Agriculture	**6,858**	**7,468**	
Annual crops	1967	2103	Added urban agriculture plots that had been classified as 'unused land'
Aquaculture Perennial Wet rice	120 1096 3675	316 1131 3918	Adjustment to current use: part of the active agricultural area had been classified as 'urban residential'
Forestry	**64,034**	**64,581**	
Production Protection Specialized	21946 8586 33502	22448 8586 33547	Minor adjustments
Water bodies	**3,028**	**3,025**	
Water Specific use	2067 681	2064 605	Minor adjustments, part of natural river had been classified as irrigation works

Land use type	Land use data Hue Uni in ha		
	Original ca. 2015	Processed according to aerial 2015	Steps of geodata processing
Irrigation works	280	356	
Green spaces / open spaces	**1,257**	**1,186**	
Cemetery Recreational parks Scenic	804 213 22	852 222 22	Minor adjustments
Sports	218	90	Partly unbuilt, subtracted 'construction land'
Other/in transformation	**6,247**	**5,586**	
Unknown	2301	18	Thoroughly analysed class unknown and allocated most of this class towards other classes, mainly 'mining' and 'industrial'
Unused Unused natural **Construction land**	3946	 2240 2536	Distinguished between natural areas dominated by vegetation, often organically formed integrated into village structures and construction land expected to be built up soon, characterised by sandy surface or covered by sparse vegetation, bordered by newly built streets
Mining		792	Had been classified separately
Built up area/urbanized	**12,630**	**12,734**	
Residential area	**6,818**	**6,817**	
Urban residential	3736	3604	Subtracted areas that are currently still under construction or different land use
Rural residential	3082	3213	Some existing 'rural residential' had already been classified as remodelled 'urban residential'
Mixed public land			
Educational, religious, health facilities, technical infrastructures (energy, waste, communication) Area of traditional belief	**3,157**	**2,949**	Subtracted areas that are currently still under construction or different land use
road space	4237	-	Unprocessed
Industry	**313**	**1,015**	
Productive factories, non-agricultural business (industry)	313	1,015	Identified industrial areas based on Land Use Plan 2020 with orientation to 2025 (QH-02), had been mostly classified as 'unknown'
Military area	**2,342**	**1,953**	
Earth defence (incl. airport) airport National defence security	2297 45	1018 890 45	Original partly vaguely demarcated polygons, subtracted airport, subtracted seaports and added to 'industry', subtracted 'mining'

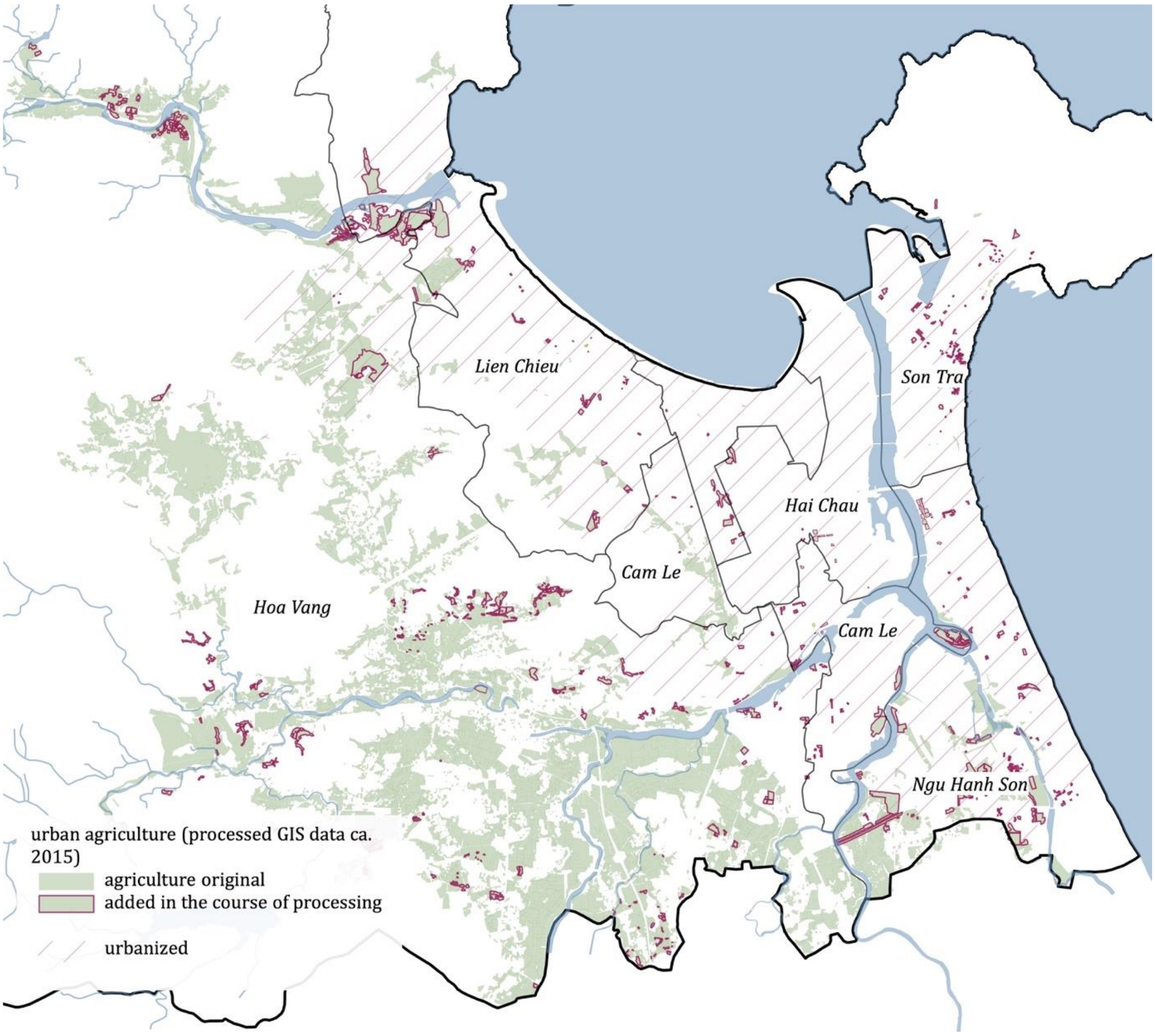


Figure 36 Overview of processed land use geodata with focus on agricultural areas

8.2.3 Matching identified typologies of urban agriculture and geodata

The following sub-sections document the iterative workflow through selected examples. Figure 37 provides an overview.

8.2.3.1 Identification of urban S1) Plots along rather natural open spaces

Upon further geodata analysis, it became clear that a portion of the agricultural areas with medium- to large-scale plots are integrated into the urban structure, almost as if urbanisation had 'skipped over' them. Field trips to selected spots demonstrated that these areas were often either meadow-like lowlands characterised by high ground-water levels or floodplains characterised by the fluvial water regime (see Figure 38).

8.2.3.2 Identification of S3 Construction / fallow land

As described in Chapter 8.2.2, a new class of construction land has been implemented to designate large spaces of transition. Construction land is rapidly changing and is often used temporarily to grow vegetables and herbs in short cycles. The assessed spaces are characterised by monotonous open soils or sparse vegetation. As such, the class does not represent entirely active agricultural patches but rather the size of the area in transition that could be used in addition for urban agriculture short-term (see Figure 39).

8.2.3.3 Identification of urban S2 farming plots

While the existing dataset covered large-scale primary production units, other types – particularly S2) Urban farming plots of long-established, neatly cultivated urban gardens – were not captured, presumably because of their semi-legal status. Hence, the polygons of the land use geodata were adjusted accordingly.

Data processing revealed that some of the agricultural plots had already been marked as built-up, while others were classified as unused land. Figure 40 illustrates the sampling of reference points of 'urban farming plots', Figure 41 and Figure 42 represent geodata processing, and Figure 36 presents a map of the total processed geodata of urban agriculture.

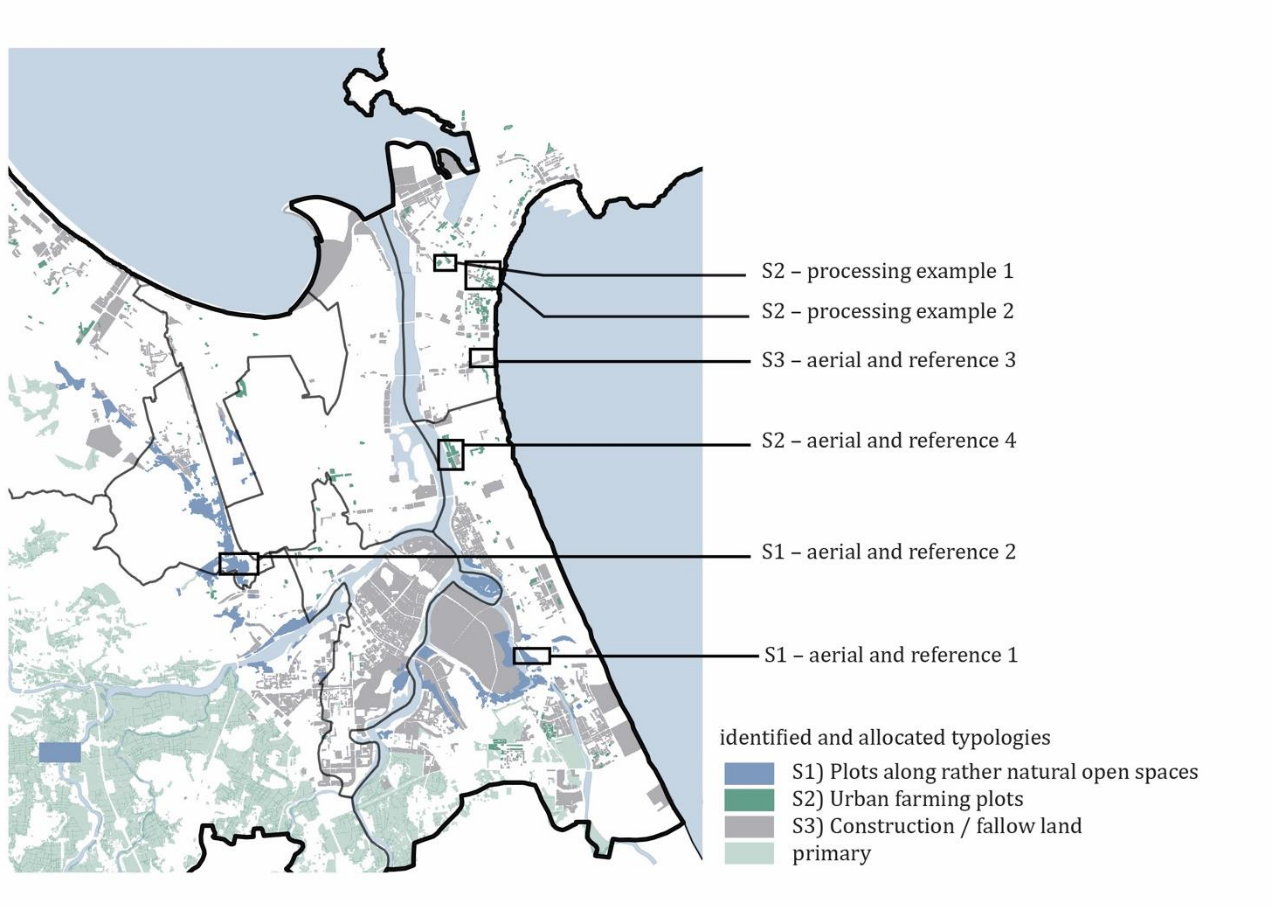
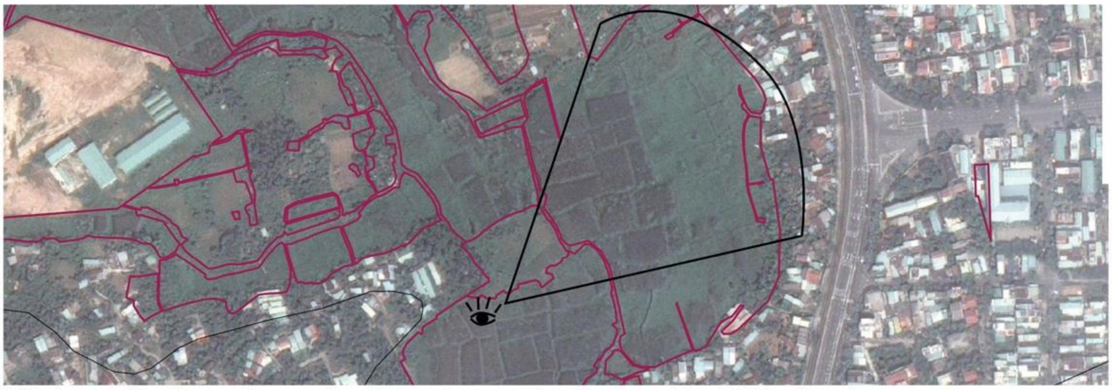


Figure 37 Overview of references and processing examples

Aerial and reference 1 - S1) Plots along rather natural open spaces, example 1

Meadow-like area



Pléiades satellite data, polygons of agricultural areas existed in the original GIS landuse data set

Aerial and reference 2 - S1) Plots along rather natural open spaces, example 2

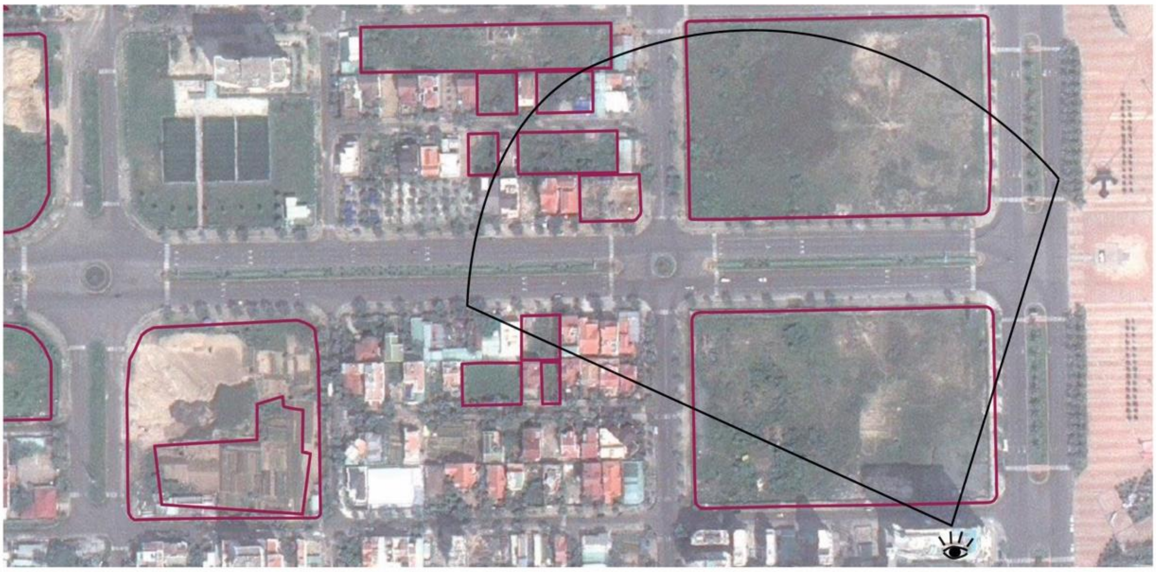
Floodplains

Pléiades satellite data, polygons of agricultural areas existed in the original GIS landuse data set

Figure 38 Aerial and reference images 1 & 2, S1) Plots along rather natural open spaces

Aerial and reference 3 - S3) Construction / fallow land, potential temporary agricultural use

Temporary agricultural use at future construction site

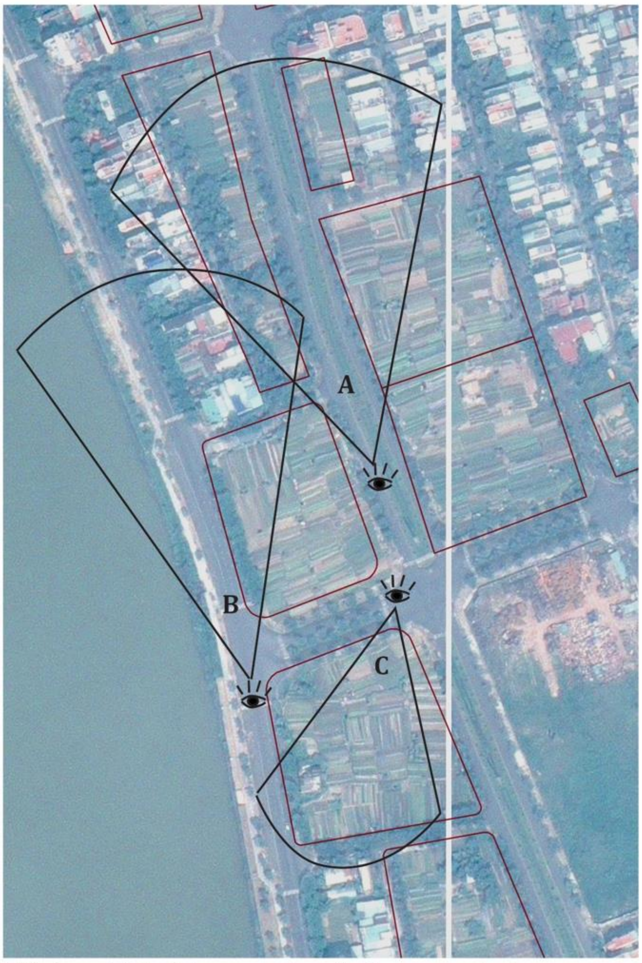


Pléiades satellite data, construction land had been classified as built-up in GIS landuse data set, processing required

Figure 39 Aerial and reference 3 – S3 construction land, potential temporary agricultural use

Aerial and reference 4 – S2) Urban farming plots

A) Large strips along the roads, Photo by Felix Vollmann / Rapid Planning



Pléiades satellite data, processing of polygons required

B) Photo by Felix Vollmann / Rapid Planning

C) Large units of S2) Urban farming plots

Figure 40 Aerial and reference 4, S2) Urban farming plots

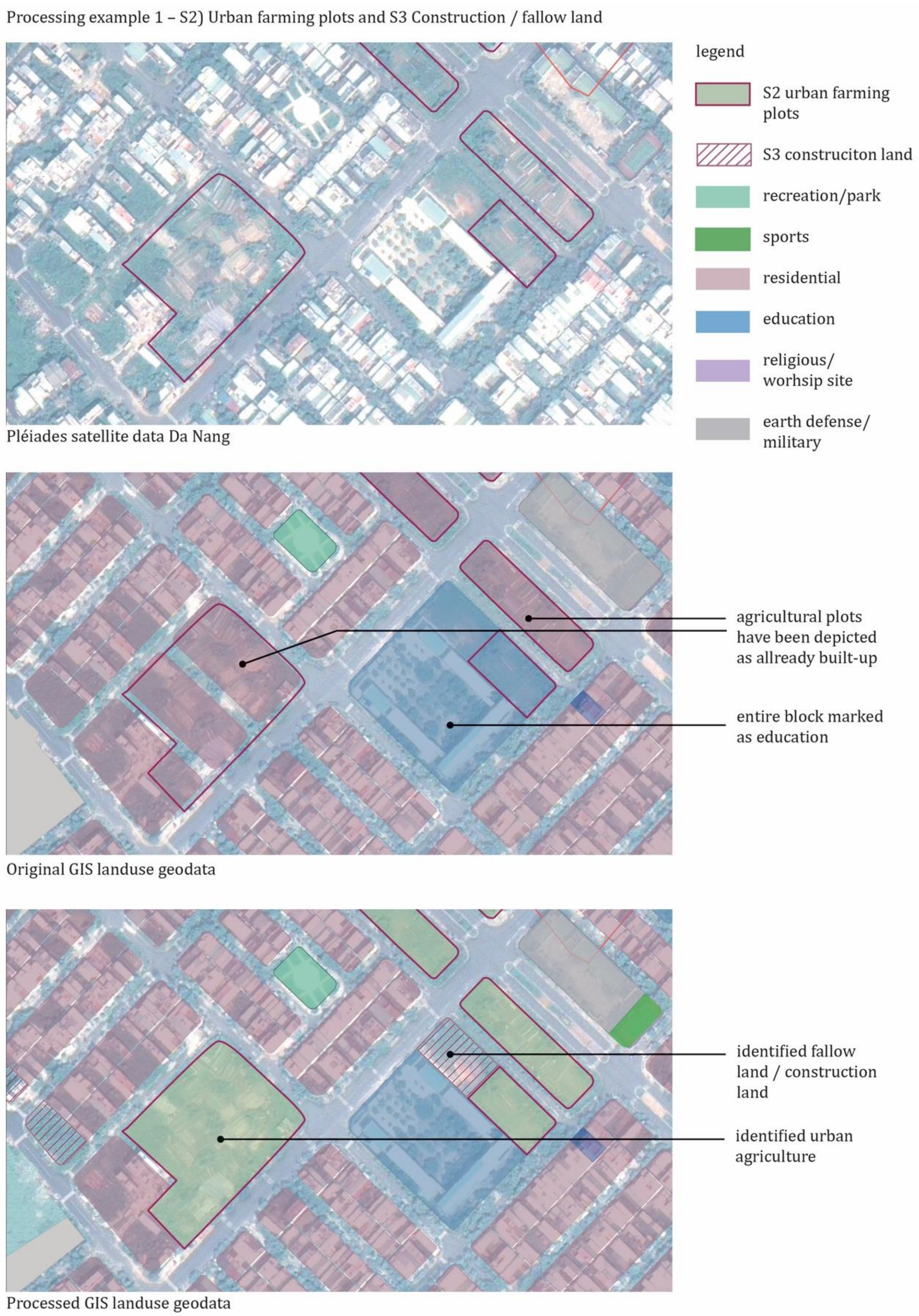


Figure 41 Processing example 1 – S2) Urban farming plots

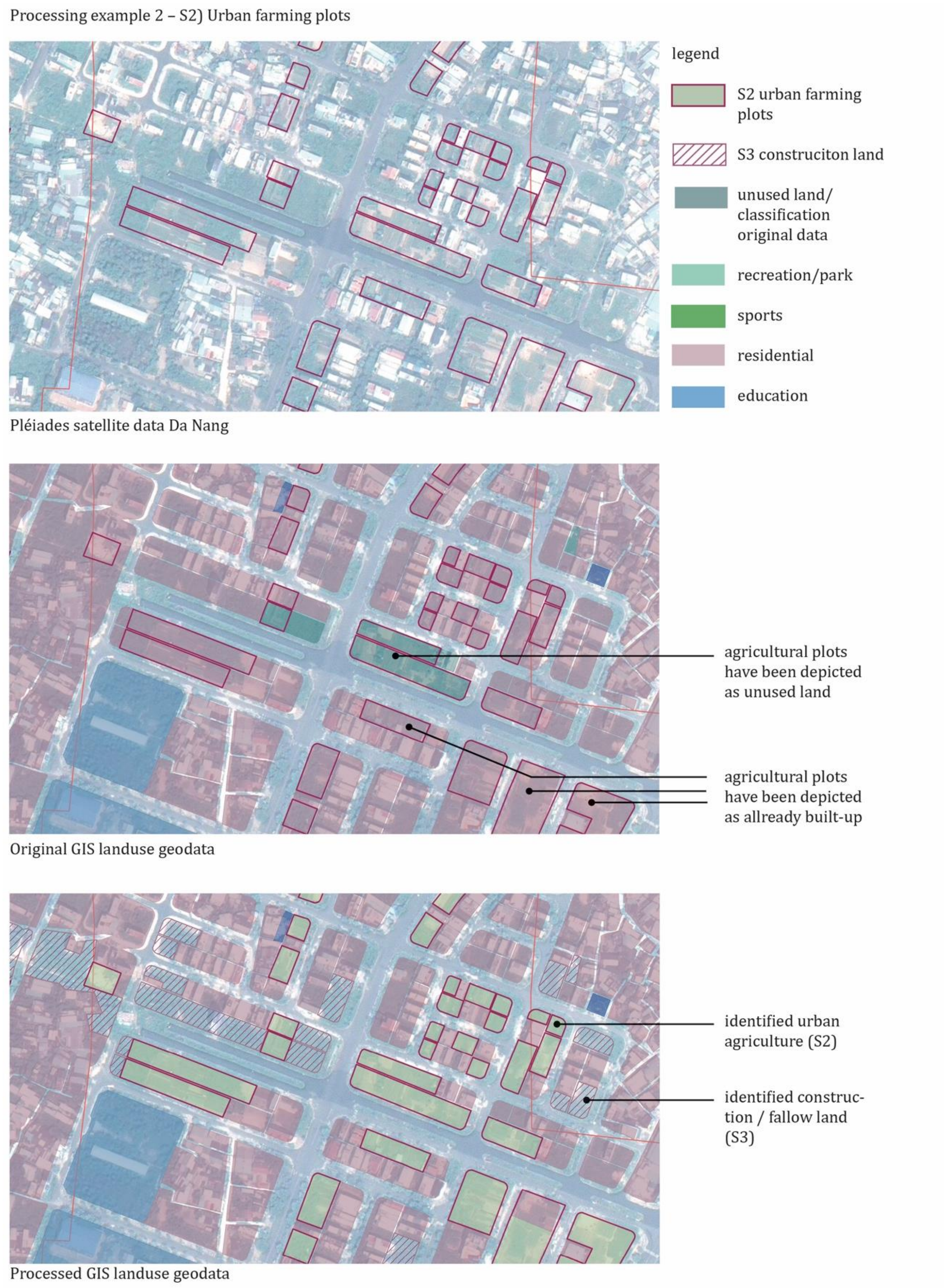


Figure 42 Processing example 2 – S2) Urban farming plots

8.2.4 Assessment of small-scale urban agriculture based on urban structure types

Assessing and processing geographic data in combination with field trips led to the conclusion that certain types of urban agriculture are too small and compartmentalised to be identified via remote sensing or aerial picture interpretation. Hence, an additional mapping methodology was tested and commissioned as a study.[25] In the study, occurrences of urban agriculture were mapped within the systemic framework of the urban structure types (USTs) and remotely sensed vegetation cover (NDVI; see 8.1.3.2), thereby allowing an upscaling of samples.

8.2.4.1 Urban structure types (USTs)

A specific objective of the 'Rapid Planning' project was to identify USTs as a spatial approach for characterising and modelling the urban morphology.[26] The University of Tübingen processed remote sensing data on spatial indices, including the share of vegetation per block, built-up areas per block and building heights. The gathered land use geodatabase offered a substantial reference for distinguishing block areas. Moreover, land use classification provided an additional parameter for aligning USTs. Ultimately, all blocks were assigned according to their structure (compact, open, industry, rural or unbuilt) based on a support vector machine. In the subsequent step, the blocks were structured according to the component's size, resulting in the following classification scheme (Braun and Hochschild, 2018, pp. 13–17):

Table 8 Classification scheme USTs (Braun and Hochschild 2018)

Size / **Structure**	**Large**	**Mid-size**	**Small**
compact	1 compact large	2 compact mid-size	3 compact small
open	4 open large	5 open mid-size	6 open small
industry	7 large industry	-	-
rural	8 rural	-	-
unbuilt	9 unbuilt	-	-

The differentiation of USTs is a simplification that intends to maintain a small number of relatively neutral classes describing the spatial pattern of residential areas, with the main factors being density (compact or open) and building size (large, mid-size, small; (Braun, 2019). As the USTs were used as a vehicle to upscale samples of urban agriculture's prevalence within urban structures, the 'rural' and 'unbuilt' classes were not relevant. Assessment of urban agriculture within these types was done through the other modes, including remote sensing of primary agriculture, aerial picture interpretation and geodata processing of medium-scale secondary agriculture.

[25] The study design was developed during the 'Rapid Planning' project for the case cities of Kigali and Da Nang by the TU Berlin team, with major contributions by research assistant Juliane Brandt. The author of this dissertation prepared and oversaw the study for the case city of Da Nang, which was carried out by former TU Berlin student Marie-Kristin Schmidt and local students Vo Luong Binh Nguyen and Le Anh Duc from the Urban Studies Division of the Da Nang Institute for Socio-Economic Development (DISED) in December 2016. Results are also documented in the deliverable report D.3.4. In this dissertation, the results are reflected upon and limitations are discussed (final report Kasper et al., 2019; deliverable report D.3.4 Lindschulte et al., 2019a)

[26] The author of this dissertation created initial UST classifications manually and contributed to providing training samples to improve the accuracy of the supervised automatic classification (Braun and Hochschild, 2018, p. 18) (see Figure 43)

Overall, the characteristics of classified USTs are as follows:

- *1) compact large:* tall dense buildings such as markets, shopping malls or social infrastructure (hospitals) within the core urban area.
- *2) compact mid-size and 3) compact small:* residential areas which largely consist of 'shophouses', the dominant building type in Vietnamese cities. Shophouses are narrow, long buildings that have only one open façade facing the street. The floor of a shophouse can be used for retail, which explains the origin of the term. Different variations exist, ranging from single-floor to detached, semi-detached and low- to midrise terraced shophouses (Downes, 2019).
- *4) open large*: tall buildings within less densely built blocks. This UST correlates with residential areas characterised by villa-style buildings with gardens as well as apartment buildings and surrounding open spaces. Furthermore, it correlates with social infrastructures such as university campuses.
- *5) open mid-size*: this UST correlates with shophouse-dominated residential areas that are less densely built. Some buildings have larger garden areas.
- *6) open small*: characterised by rather small shacks. This type occurs rarely, and it is assumed that it represents mostly older and tendentially lower-income structures.

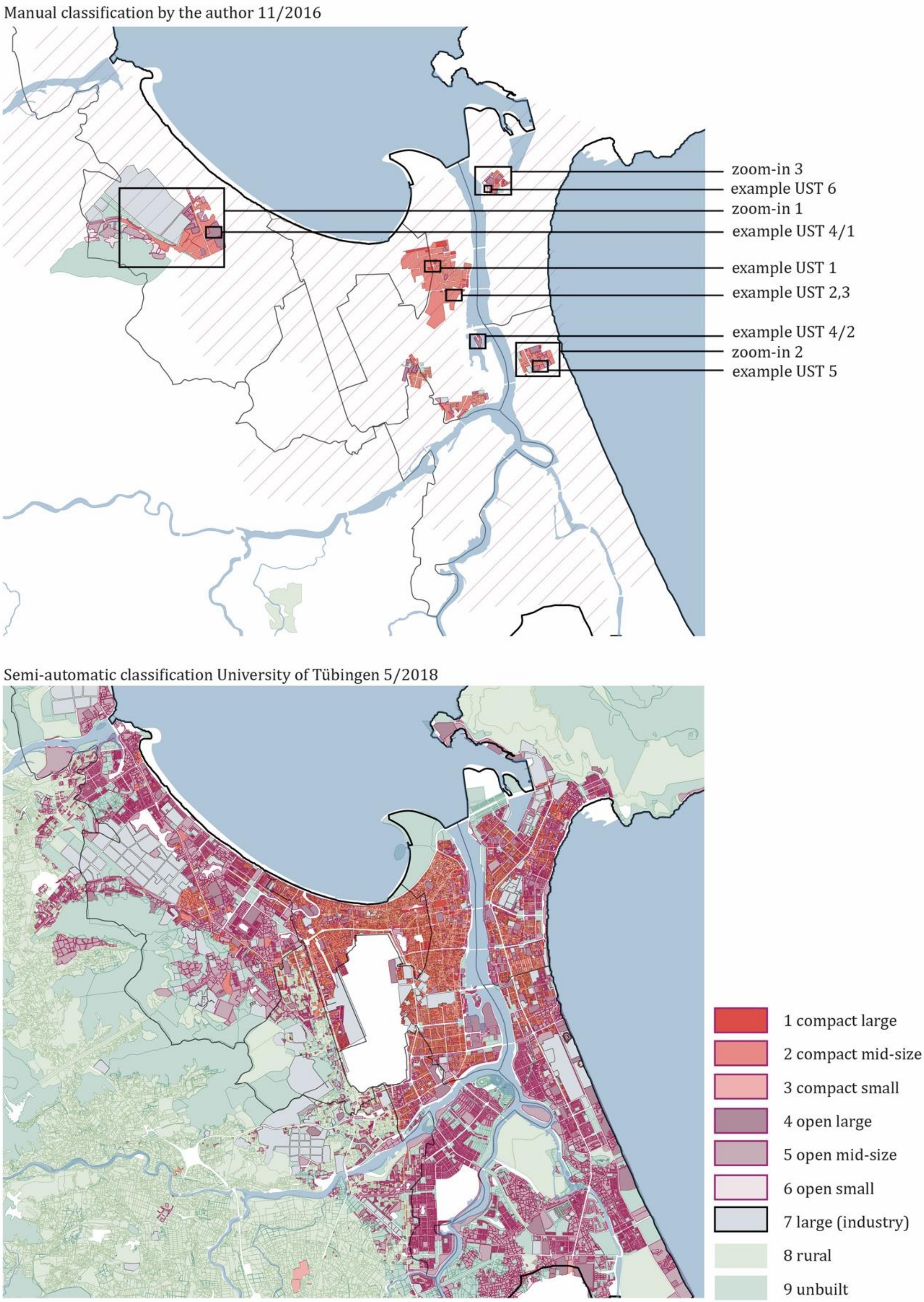


Figure 43 Overview of manual UST classification by the author and semi-automatic classification by the University of Tübingen

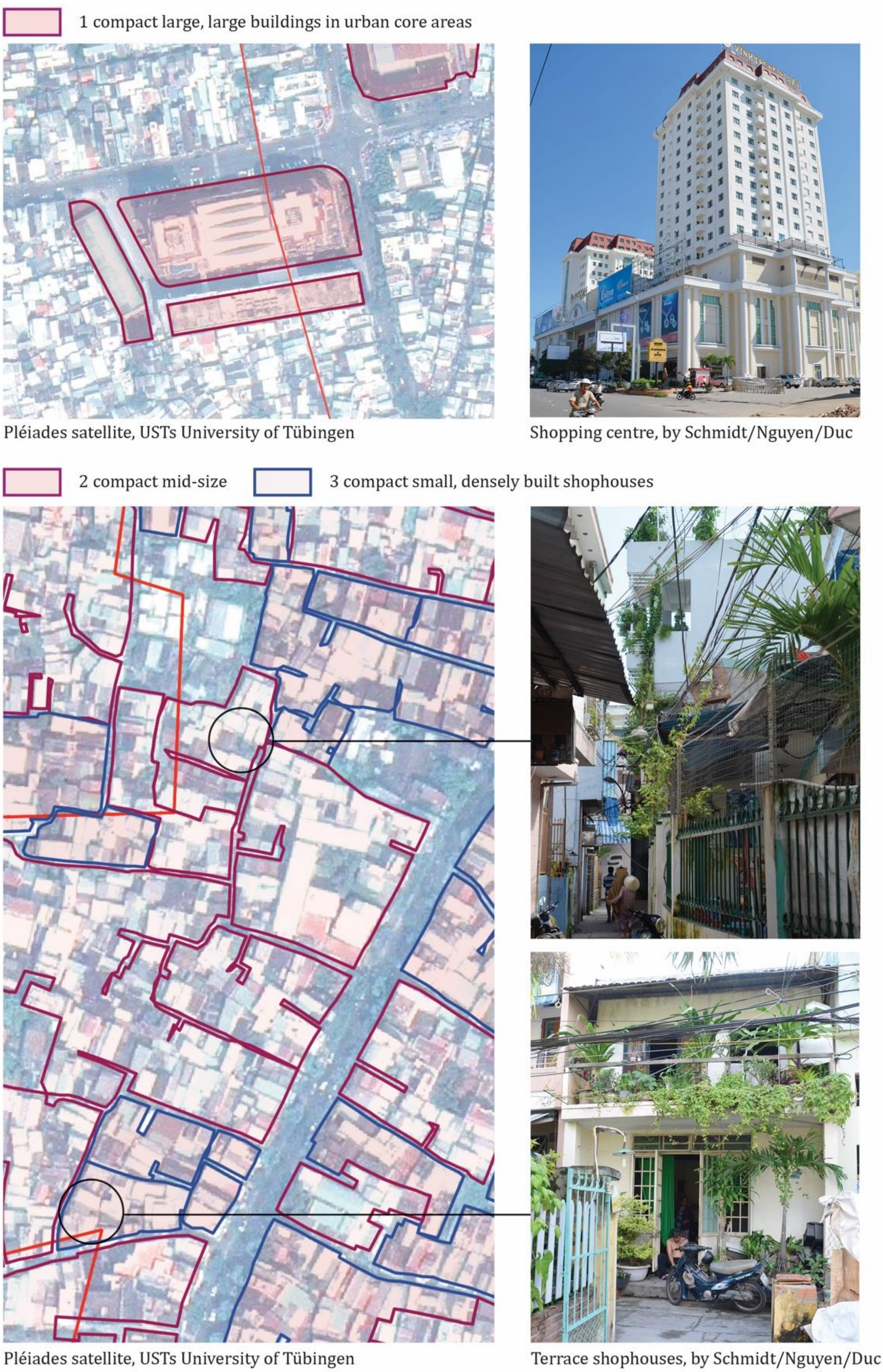
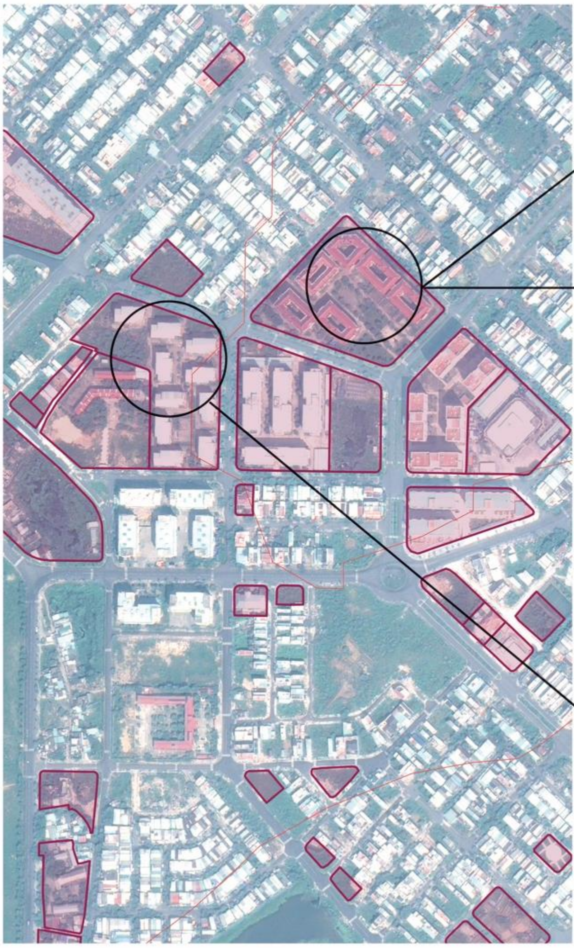


Figure 44 Examples of UST 1 compact large classification, UST 2 compact mid-size, and UST 3 compact small. UST 2 and 3 could not be distinguished through manual aerial picture interpretation as they are very similar and mostly differ regarding building height, which can only be systemically assessed via remote sensing

4/1 open large - appartment buildings

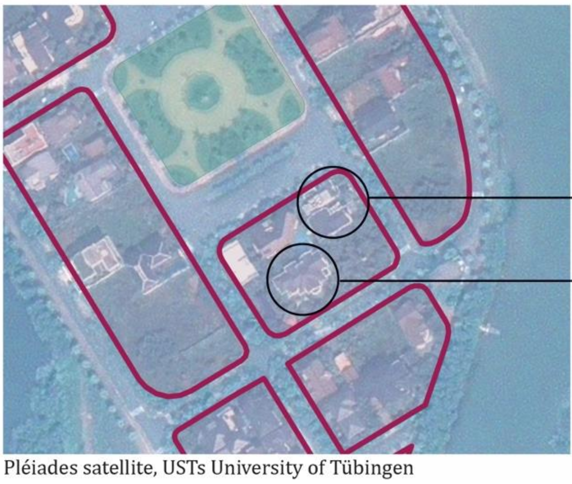


Pléiades satellite, USTs University of Tübingen

Appartment block with green yard, by Schmidt/Nguyen/Duc

Appartment with vegetable garden, by Schmidt/Nguyen/Duc

4/2 open large - villas with garden



Pléiades satellite, USTs University of Tübingen

Villas, by Schmidt/Nguyen/Duc

Figure 45 Examples of UST 4 open large classification

Figure 46 Example of UST 5 open mid-size classification and UST 6 open small

8.2.4.2 Mappings

Classification of typical USTs and assessment of vegetation cover (NDVI) offer a potential vehicle to assess the spatial manifestation of small-scale urban agriculture that cannot be identified by remote sensing or aerial picture interpretation. The 'Rapid Planning' project allowed testing of this procedure by documenting samples of the prevalence of urban agriculture in the USTs and upscaling the information. Overall, 175 sample plots in eight different areas of the city were documented using photographs, notes and location. For each sample plot, the share of space used for urban agriculture was roughly estimated and divided into three categories: low, medium and high.

8.2.4.3 Limitations and final evaluation of mapping data and further processing

There are several limitations to the study, which is why the results are reliable only to a limited extent. However, the mapping could not be repeated due to limited resources. Nonetheless, within this thesis, a final evaluation was carried out to interpret the results and use them for an approximation of the spatial extent of this typology, and the process is discussed as a potential methodology as part of the PGI approach.

First of all, mapping and especially quantification of small-scale urban agriculture, such as small residential gardens or building-related entities (balconies, yards), and the use of public spaces pose a challenge due to the enormous heterogeneity of elements and the difficulty of distinguishing between ornamental and edible plants. In the case of villas, properties are surrounded by walls, which exacerbates the difficulty of investigating the prevalence of urban agriculture.

Distinguishing between the limited number of 'low, medium and high' categories was too imprecise and impractical. In addition, the number of samples taken in the UST of each testing area was small, which means that the level of representation is limited.

A final evaluation utilising the collected data was conducted when the supervised automatic UST classification and remote sensing of the vegetation cover were finalised. This enabled an upscaling of UST-based information and additional 'stabilisation' of findings through correlation with vegetation cover.

The UST classification was conducted for the entire city. To increase the accuracy of the results, the focus was set on built-up residential areas for several reasons. First, referencing land use data categories and actual spaces connects to the city's official planning data and also allows the projection of planned residential extension areas. Residential areas were chosen because the goal of the mapping was to characterise and tentatively quantify the typology of small-scale urban agriculture performed by citizens within their immediate living environment. As other researchers have observed, in Da Nang urban agriculture takes place in residential areas (Kohlbacher, 2015, p. 30).

Hence, further evaluation of mapping results was narrowed to areas classified as 'urban residential' in the official land use dataset. As UST classification was based on the official land use plan, the original database was maintained, which allowed selection of UST polygons with the residential attribute (Figure 47). In this way, mapping results were not confused with other land use categories such as construction land (see 8.2.3). The selection also changed the composition of USTs given that UST 2 compact mid-size, UST 3 compact small, and UST 5 open mid-size correlate with residential areas. Only about a quarter of the open large UST 4 polygons remained, which were more likely to represent residential areas (villas with gardens and apartment complexes) and to exclude other public facilities and social infrastructure (e.g., university campuses). However, this also means that the data's informative value was reduced to 'residential' areas, and any urban agriculture that may occur in other land use categories such as 'educational' was no longer taken into account.

Based on remote sensing of the vegetation cover, the mean green cover ratio of the selected residential USTs was calculated. Next, the approximate share of urban agriculture within that green cover was estimated for the investigated USTs in the different testing areas. The estimation values range from 0% to 15%, replacing the initial 'low, medium, high' categories. This estimation was based on comparing and assessing the results of the single sample plots, normalising outlying data of single samples, and studying the descriptive mapping booklet. While the final result was based on an estimated share of urban agriculture from observation through mappings, validity was enhanced by leaning on a) the strategic assessment of different, representative USTs within the city and b) the results of remote sensing of vegetation cover, which provide a representative database of green spaces. Naturally, the prevalence of urban agriculture correlates with higher levels of vegetation and lower densities as these environments provide more opportunities to cultivate crops (Table 9).

The mappings served to derive an estimated total quantity of productive small-scale spaces within residential areas, which can now be considered when estimating the city's total productivity and assessing elements shaping the urban metabolism. The estimation was rather conservative and, given the obvious popularity of urban agriculture in Da Nang, does not seem too high. Still, small-scale urban agriculture entities may comprise approximately 100 ha, which equals an average share of around 2.8% of the total urban residential area.

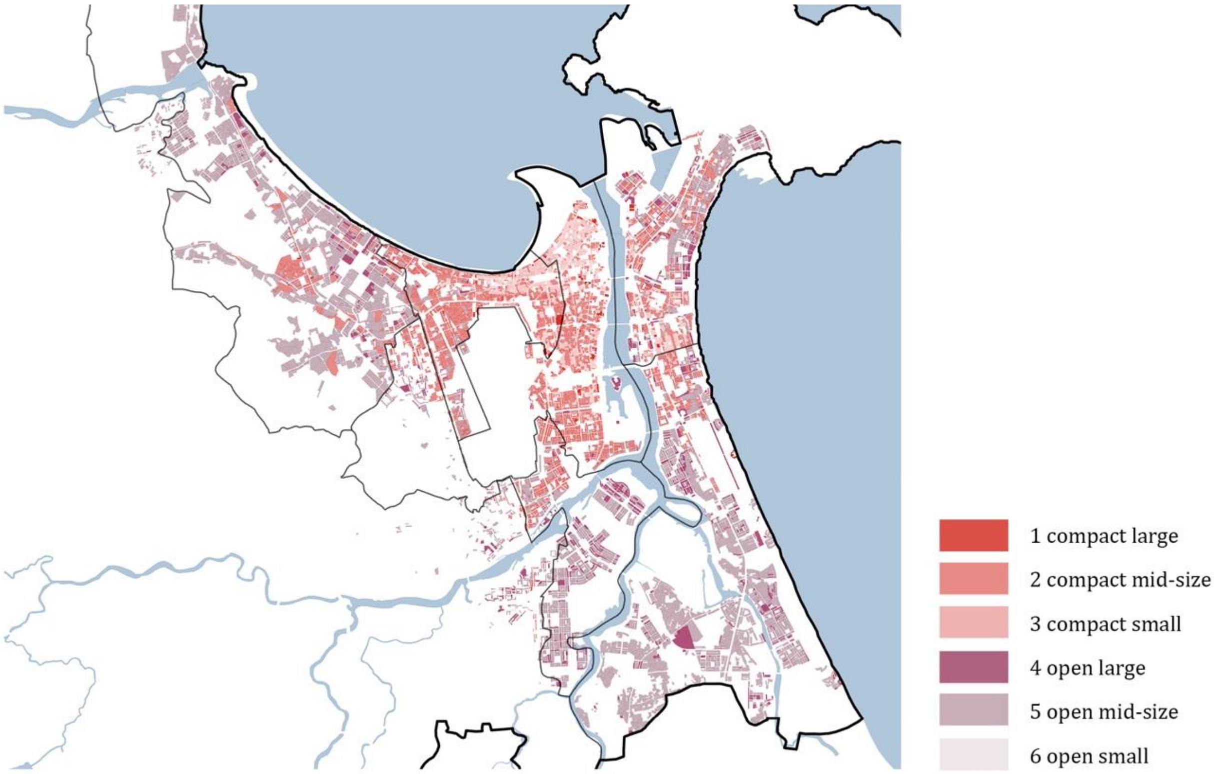


Figure 47 Selected UST polygons classified as residential according to land use geodata

Table 9 Estimation of the USTs' share of urban agriculture for vegetation

Urban structure type	Total area of urban structure type ha	Total area of urban structure type classified residential ha	Average share of Vegetation in UST %	Total area of vegetation in urban structure types ha	Average share of urban agriculture of vegetation in UST %	Total area of urban agriculture in UST ha	Total share of urban agriculture in UST ha
1 compact large	97	26	5.70%	1.48	2%	0.02	0.08%
2 compact mid-size	1.035	980	3.50%	34.3	5%	1.72	0.18%
3 compact small[27]	407	332	1.0%	3.32	5%	0.17	0.05%
4 open/large	1.140	268	49.30%	132.12	5%	6.61	2.47%
5 open/mid-size	3.667	2193	44.72%	980,70	10%	98,07	4.47%
6 open/small	80	9	37.67%	3,4	15%	0.51	5.67%
sum	6.019	3811,2				107,1	2,80%

[27] UST 3 compact small could not be distinguished from UST 2 compact mid-size by provisional UST classification

8.2.5 Final alignment with agricultural production statistics

The previous sections explained how the spatial extent of urban agriculture typologies was assessed and how their extent was estimated. To comprehend the productivity of these areas in terms of food supply for the city and urban food system planning, it is necessary to align the relevant data with the official agricultural census. While the census is relatively detailed regarding primary 'regular' agriculture, it does not capture the full extent of secondary agriculture.

Table 10 presents the datasets of the statistical yearbook and the original land use data used by authorities, which was discussed in 8.1.3.1. in comparison with the land use data processed in this thesis.

Secondary urban agriculture is mostly used for vegetable production. A challenge of aligning the data is that information on the production of vegetables (leafy or stem vegetables, fruit-bearing vegetables and roots; e.g., lettuce, tomatoes, carrots) is sparse and not included in the statistical yearbook. To overcome this challenge, additional information was obtained through expert meetings and the commissioned study.[28] The Department of Agriculture and Rural Development designated an area of 121 ha for vegetable production. It is assumed that these production sites are located within primary agriculture areas. At least 75 ha alone account for the production of 'safe vegetables' in rural Hoa Vang (see 8.1.1.2), which suggests that there are at least 46 ha more ha of regular vegetable production in Hoa Vang.

Table 10 Agricultural production, comparison of existing datasets and the processed land use data

Districts	Statistical yearbook 2015 section p. 245 ff.						Statistical yearbook 2015 section 126 ff., sum of planted areas of crops + 121 ha vegetable production	Statistical yearbook 2015 section 3	Processed GIS land use data, ca. 2015	Original GIS land use data, ca. 2015
	Available statistics of selected products, area in ha							Total production area including aquaculture in ha		
	Aqua-culture	Cereals	Sweet potato	Cassava	Peanut	**Sum**				
Total	**470**	**5757**	**332**	**171**	**512**	**7,242[29]**	**8,225**	**6,811**	**7,468**	**6,858**
Lien Chieu	60	36	9	-	7	118		203	326	208
Thanh Khe	-	-	-	-	-	-		5	12	0,6
Hai Chau	-	-	-	-	-	-		8	10	0
Son Tra	-	-	-	-	-	-		25	26	3,5
Ngu Hanh S.	10	277	-	25	97	416		505	547	482
Cam Le	1	128	-	-	9	139		232	152	105
Hoa Vang	399	5316	323	146	399	7,261		5,833	6,392	6,058

Considering the urban districts of Thanh Khe, Hai Chau and Son Tra, the comparison confirms that agricultural areas classified as 'unused land' or already 'built-up' land in the original GIS data were, in fact, productive plots. On the other hand, some areas that were already labelled as 'built-up' or 'unused' in Lien Chieu had apparently not been included in the statistics.

With this added information, the total crop area of single reported crops and aquaculture amounts to 8,225 ha, revealing a gap in data given the 7,468 ha identified through spatial assessment.

To bridge this gap, the following assumptions are made.

1. It is assumed that the reported production of single crops, which add up to 8,225 ha, represents the typology 'P1) primary', meaning large-scale regular agriculture located on the outskirts of the urbanised area, much of which large parts belong to the Hoa Vang District, including the 121 ha of vegetable production.
2. It is assumed that these statistics do not cover the identified typologies of secondary urban agriculture that produces vegetables.

[28] Commissioned study of TU Berlin, carried out by TU Berlin student Marie-Kristin Schmidt and local students Vo Luong Binh Nguyen and Le Anh Duc of the Urban Studies Division of Da Nang Institute for Socio-Economic Development (DISED)

[29] Not including all crops as data per district is only available for selected crops

3. To match the calculated spaces of the typologies with food production, it is assumed that S2) Urban farming plots and S4) Small-scale urban agriculture only produce vegetables. Furthermore, it is assumed that a third of S1) Plots along rather natural open spaces are used for vegetable production, while the rest serve as meadows or for rice cultivation. These are model-like simplifications as it has been observed that, for example, maize belonging to the category of cereals and fruit trees can occasionally occur in S2) Urban farming plots. However, crop cultivation schemes are flexible, and this analysis serves to understand the assessed space's potential.

Finally, the resulting spaces are multiplied with known yield rates (t/ha/a) based on the local agricultural census. In the case of vegetables, the yield rate refers to the average national yield (17.2 t/ha/a) according to the FAO (FAOSTAT, 2017).

Table 11 Crop production in Da Nang, 2015 (Da Nang statistics office. 2016; *DARD, 2016 **FAOSTAT, 2018, ***outcome of spatial assessment within this research)

	ha	t/a	t/ha/a	Import into Da Nang
***Primary* production**	**8,225**			
Aquaculture	**470**			
Cereals	**5,757**	**33,785**	**5.9**	
Rice	5,377	31,645	**5.9**	
Maize	380	2140	**5.6**	
Vegetables and fruits (including starchy roots)	**930,9**	**11,224.3**	**12.1**	**127.750***
Vegetable[30]	**121***	**2,081**	**17.2****	**73,000***
Starchy roots	**503**	**3,145**	**6.3**	
Sweet potato	332	2.081	**6.3**	
Cassava	171	1.064	**6.2**	
Fruit	**307**	**6,053**	**19.7**	**54,750***
Orange	31	124	**4.0**	
Banana	201	5.411	**26.9**	
Mango	62	100	**1.6**	
Pineapple	13	418	**32.2**	
Industrial crops	**917**	**14,745**	**16.1**	
Cashew	24	90	**3.8**	
Peanut**	512	969	**1.9**	
Tobacco	13	24	**1.8**	
Coconut	36	655	**18.2**	
Sugar cane**	332	13,007	**39.2**	
Beverage/spice crop	**151**	**234**	**1.5**	
Tea	76	201	**2,6**	
Pepper	75	33	**0.4**	
***Secondary* production**	**323**	**5,555**	**17.2*****	
'Secondary' vegetable and fruits [31]				
S1) Plots along rather natural open spaces	**120**	**2,064**	**17.2*****	
S) Urban farming plots	**80**	**1,376**	**17.2*****	
S3) Construction / fallow land[32]	**-**			
S4) Small-scale urban agriculture	**100**	**1,720**	**17.2*****	
S5) Rooftop gardens	**23**	**396**	**17.2*****	

[30] Leafy and fruit vegetables, e.g., lettuce, tomato, cabbage

[31] Rounded, S1) 121.44 ha; S2) 81.5 ha; S4) 107.1; S5) 46

[32] Active elements within construction land are assessed in the form of S2) or S4). Construction land is understood as a potential space for additional temporary urban agriculture

8.3 Results of the case study: Finalised description of urban agriculture typologies

Identifying typical recurring features of urban agriculture structures, defining typologies and developing procedures to assess their spatial extent results in the following description of urban agriculture in Da Nang.

8.3.1 P1) Primary agriculture

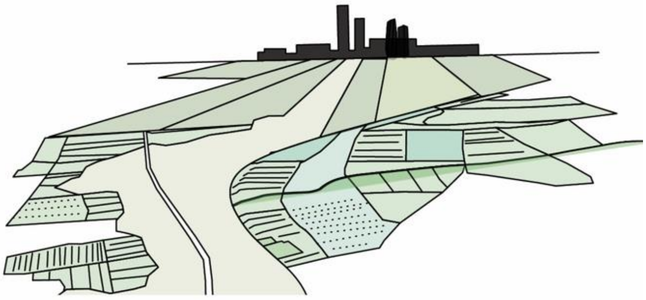
Large areas of Da Nang's extensive territory are still under professional farmers' management for more or less 'traditional' agriculture. In this context, this type of agriculture carried out in dedicated areas according to land use plans is considered *primary* (see also 8.2.1). Production sites and yielded crops are covered by official statistics. Based on an extended review of existing statistics, this area was calculated as accounting for 7,756 ha of Da Nang's territory in 2015. Almost three quarters of the area is used for rice production, followed by so-called industrial crops (mainly cashews, peanuts and sugarcane) and other vegetable and fruit production. Everything known about agricultural production in Da Nang relates to this production typology (see 8.1.2).

Size/ scale	Type	Purpose	Products	Special features	Assessment methodology	Assessed size in ha
Large-scale, plots > 5 ha	prim ary	rather market-oriented	cereals, industrial crops, fruits & vegetables, animal products	'regular' agriculture, covered by official statistics.	review of statistics and geodata processing	7,756

P1) Primary agriculture

Paddy fields

Overview structure of primaty agricultural land and villages



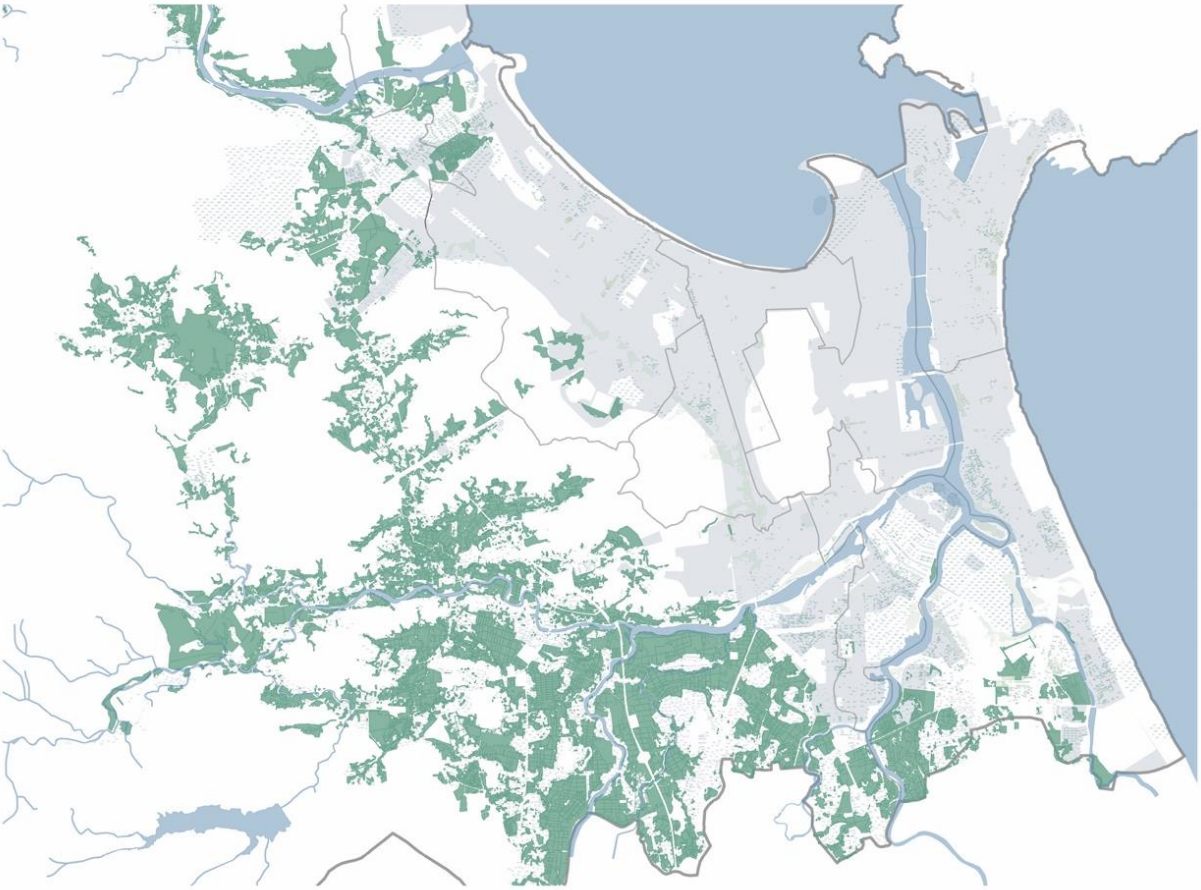


Figure 48 Cartographic und illustrative depiction of P1) primary agriculture

8.3.2 S1) Plots along rather natural open spaces

The S1) typology represents large- to medium-scale agricultural units partly included in official land use geodata. The areas are integrated into the urban structure as if urbanisation had 'skipped' them; this is because the typology features either meadow-like lowlands or is located along the riparian zone. Because of this, the areas are characterised by either high ground-water levels or the fluvial water regime.

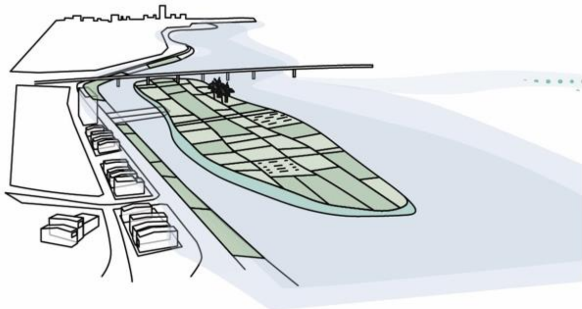
A representative example of the S1) typology is an island on Cam Le River that is cultivated by a safe vegetable cooperative with funding of the Asian Development Bank. The island is officially designated for vegetable production as it is prone to flooding during rainy season and unsuitable for urban development. It has low terrain and a soft embankment. The long-term perspective has enabled the famers to invest in pumps extracting water from the river.

It can be assumed that this typology's elements, particularly the meadows running parallel to the city centre (in the north-west south-east direction), contribute to mitigating urban flooding by infiltration of urplus rainwater and providing retention space. The typology has the potential to further qualify as a type of blue-green infrastructure (see 3.5.2).

Size/ scale	Type	Purpose	Products	Special features	Assessment methodology	Assessed size in ha
Medium /large-scale, plots 1 to > 5 ha	secon dary	rather market-oriented	cereals, industrial crops, grazing it is assumed that about 1/3 of the S1 areas are used for fruits & vegetables	geography emphasis: water-related units, meadow or riparian zone	sampling references during field trips and geodata-processing	360

S1) Plots along rather natural open spaces

Temporary flooded island, by Thomas Sterr / Rapid Planning



Grazing in meadow

Figure 49 Cartographic und illustrative depiction of S1) Plots along rather natural open spaces

8.3.3 S2) Urban farming plots

Urban farming plots represent a locally specific type of space in which entire blocks or portions of blocks are dedicated to urban agriculture as a temporary use of vacant lots. Although urban farming plots are excluded from official statistics, the utilisation of vacant lots is allowed in Da Nang. The plots are managed by authorities of the ward, and permission must be obtained for temporary agricultural use. While agricultural land generally belongs to the state and can only be leased, there is mostly no leasing fee for the use of vacant lots. An exception to this is the case of high profits from the produce yielded by using the plot, in which case a low fee has to be paid in negotiation with the Ward (Kohlbacher, 2015, p. 31).

There are similarities to S3 and the temporary use of current construction land, but this typology is characterised by a more established character, with farming plots persisting for years; this is also evident from existing banana groves and established infrastructures in the form of sheds. Other reoccurring elements are compost heaps and water-collection ponds below the banana groves. Typically, plots are surrounded by seemingly wild grass that shields the plots from view and potential pollution. When walking alongside the plots, they are hardly noticeable, and it is surprising to see the neatly cultivated rows of vegetables and herbs behind the wild grass. The size of single plots accounts for 0.025 ha to approximately 5 ha. The plots are visible in aerial pictures and are assessed using manual aerial picture interpretation, geodata processing and sample collection.

The plots resemble community gardens or allotments. The frequent wild grasses presumably contribute to providing habitats for insects and avifauna and to shielding the produce from potential pollution from traffic. These types of plots are currently not very visible and are not intended to be accessible by the public. As the typology is mostly distributed in condensing residential areas in older parts of Da Nang, their formalisation presents a unique opportunity to improve the supply of green spaces.

Size/ scale	Type	Purpose	Products	Special features	Assessment methodology	Assessed size in ha
Medium-scale plots 0.025 – 5 ha	secon dary	both for selling and own supply	mainly fruits & vegetables	parts of or entire blocks used for neatly cultivated vegetables and fruits	sampling references during field trips and geodata-processing	80

S2) Urban farming plots

Figure 50 Cartographic und illustrative depiction of S2) Urban farming plots

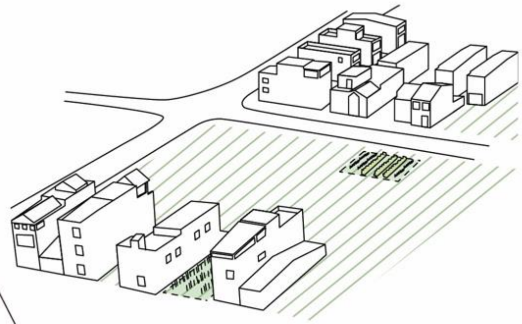
8.3.4 S3) Construction/fallow land

The current dynamics of urban expansion have been perceived to overexploit land and exceed demand (see 7.5.1). As a result, enormous amounts of land in Da Nang are currently characterised as fallow or construction land. The geodata processing indicated that approximately 2,500 ha are allocated as 'construction land'. These areas are characterised by a sandy surface or sparse vegetation and are located within urban areas or urban extension areas, and they have been visibly prepared for further development by newly build roads (see 8.2.2). Oftentimes, single plots are already built on. The size of construction land changes constantly. It has been observed that construction land is utilised temporarily to grow vegetables or herbs in short cycles.

The current use for this type of agriculture cannot be assessed, but there is a sense in investigating the strikingly prevalent vacant land's total dimension. Its temporary utilisation could be encouraged by the City of Da Nang to harness the benefits of urban agriculture, including increased livelihood resilience for small-scale producers and resource efficiency for land and food.

Size/ scale	Type	Purpose	Products	Special features	Assessment methodology	Assessed size in ha
Medium-scale plots 1–5 ha	secon dary	both for selling and own supply	mainly fruits & vegetables	temporary use of future construction land	sampling references during field trips and geodata-processing	2,536

S3) Construction / fallow land



Temporary use of fallow land

Overview of large newly designated urban extension

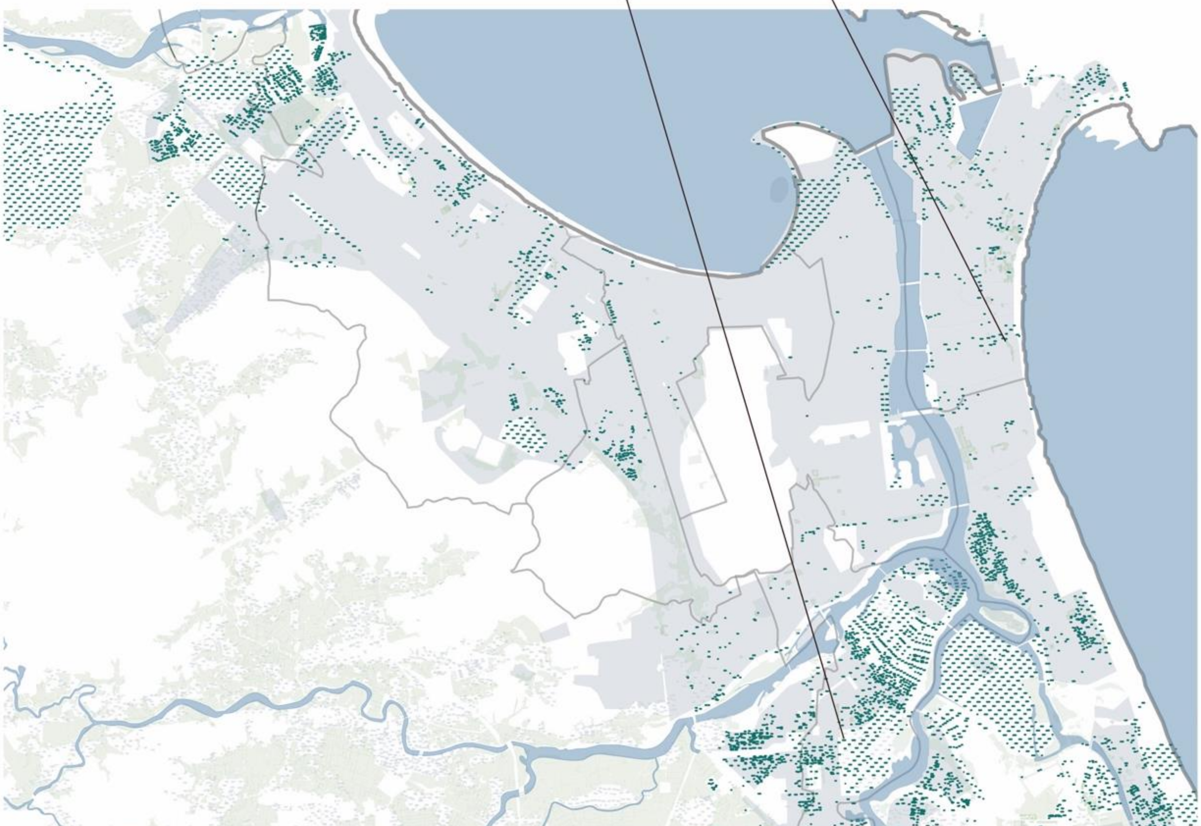


Figure 51 Cartographic und illustrative depiction of S3) Construction/fallow land

8.3.5 S4) Small-scale urban agriculture

Growing vegetables and fruit is part of many citizens' everyday life in Da Nang, resulting in high prevalence and diversity of small-scale urban agriculture. This diversity does not match a single typology as defined in this dissertation. Rather, S4) Small-scale urban agriculture is a collective term for all kinds of uses that evade assessment methodologies based on remote sensing. Contrary to the previously described typologies, S4 had to be assessed by leaning on automatically supervised classification of urban structure types (USTs) and by conducting mappings within these structures to upscale the information (see 8.2.4).

From a planning perspective, the S4 typology can be divided into the utilisation of private plots and the utilisation of public spaces. Residential gardens occur in older parts of the city as well as in more rural areas. Traditional single-family buildings equipped with gardens were presumably predominant in Da Nang before current rapid urbanisation processes. Hence, S4 land is rapidly declining. This type of settlement likely correlates with the assessed open small UST, which has relatively high share of urban agriculture. A small share of residential areas manifest as apartment buildings with common outdoor spaces, which correlate with the open large UST. It has been repeatedly observed that these outdoor spaces are utilised for urban agriculture. The now dominant shophouse structure features small porches, often equipped with Styrofoam boxes or ceramic tubs to grow vegetables like climbing beans, spinach or lettuce.

Moreover, various forms of small-scale urban agriculture in public spaces have been observed, ranging from installing small containers along the pavement, using 'leftover' green spaces between a property and the sidewalk, and using green spaces associated with roads or riverbanks In this context, a religiously motivated culture for appropriating public green spaces is apparent. In many corners of the city, places are used for ceremonial purposes, such as for burning sacrificial offerings or establishing small shrines with ceremonial gifts such as fresh fruit and candles.

The extent of these often very small units was estimated to reach a total of about 100 hectares (see 8.2.4). The typology is highly characterised by the activities of individual residents interested in growing their own food. Its relevance to overall urban planning is limited, but it can be interpreted as evidence of citizens' desire to tend to green spaces and grow food. This enthusiasm provides opportunities for co-creating and co-maintaining public productive green spaces. Moreover, increasing the share of residential gardens to improve the supply of green spaces is a declared goal in urban planning (see 7.3.2.4).

Size/ scale	Type	Purpose	Products	Special features	Assessment methodology	Assessed size in ha
Small-scale residential gardens					mappings and upscaling based on USTs	100
small scale < 1 ha	secon dary	own supply	mainly fruits & vegetables, animal products	Traditional residential, use of common spaces of apartment complexes, use of porches on shophouses		
Small-scale urban agriculture on public space						
small scale < 1 ha	secon dary	own supply	fruits & vegetables	utilisation of public open space (e.g., sidewalks, vacant lots)		

S4) Small-scale urban agriculture

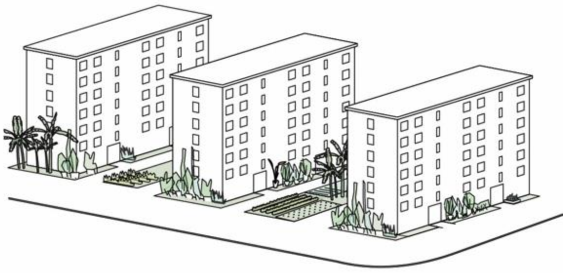
S4.1) Residential gardens

Traditional garden, old building in urban area

Traditional garden, old building in urban area

Garden in rural area, by Schmidt/Nguyen/Duc

Garden in yard of multistory building, by Schmidt/Nguyen/Duc



Garden in yard of multistory building

Figure 52 Illustrative depiction of S4.1) residential gardens

S4.2) Public space

At a roadside

Garden adjacent villa at a public riverbank

Use of „leftover“ green between pavement and wall

Styrofoam boxes at pavement

Claim of entire sidewalk section

Fruit trees (background) and tomatoes in street tree bed

Appropriation of public green is part of the local culture

Figure 53 Illustrative depiction of S4.2) small-scale urban agriculture in public space

8.3.6 S5) Rooftop garden

Rooftop gardens are a common phenomenon and substitute for previously common soil-bound residential gardens. Similar to other urban agriculture practices, these gardens are motivated by the desire to self-supply with fresh and 'clean' food (Kohlbacher, 2015, p. 30). The now dominant shophouses often feature terraces or accessible roofs.

As rooftops cannot be seen from the ground, their assessment was not included in the mappings. Instead, the University of Tübingen identified the total number of shophouses based on aerial images from 2015 (about 230,000 shophouses) and calculated the total space they occupy, estimated to be approximately 2,317 ha. Further simplified calculations were carried out to estimate the total space of shophouses according to the planned urban extension of the Urban Masterplan. Of the 6,736 ha extension area designated, about 60% will account for buildings (with 35% road space and 5% parks), resulting in an additional 4,000 ha of building space in 2030. These are just rough estimations, but they allow calculation examples. For instance, what if 2% of current rooftop space or 2% of rooftop space in 2030 were used for urban agriculture – how much would this contribute to the city's food supply?

Size/ scale	Type	Purpose	Products	Special features	Assessment methodology	Assessed size in ha
Small -scale < 1 ha	secon dary	mostly own supply	fruits & vegetables	use of rooftops	assessment of total size of shophouse building by University of Tübingen	if 2% of the 2,317 potential rooftop spaces are used for urban agriculture, this would represent 46 ha

Rooftop garden, by Schmidt/Nguyen/Duc
Rooftop garden with plant shading
The dominant shophouse structure has flat roofs, often equipped with a terrace or loggia

Figure 54 Illustrative depiction of S5) Rooftop gardens

8.4 Consolidated overview of urban agriculture's role in Da Nang's urban food system

Urban agriculture's actual contribution to the Da Nang City's food supply is unknown due to a lack of knowledge of the total spatial extent of urban agriculture and its productivity. Bringing together the assessed spaces and average food consumption statistics (8.1.2.3) allows the derivation of approximate food self-sufficiency rates.

Based on this calculation, the self-sufficiency rate for vegetables is 7% and for fruits is 15%, which are lower than the estimated 35% self-sufficiency rate given by the local authority DARD (Bilateral meeting with DARD, 17.3.2015). These rates might be based on national consumption statistics, stating low quantities of consumed food, which do not seem adequate. According to these statistics, people eat an average of 67 grams of vegetables per day, whereas the provision goal is an average of 328 grams of vegetables per day (see 8.1.2.3). Assuming such low consumption rates increases the estimated self-sufficiency rate to 51% for fruit and 14% for vegetables (Table 12).

Another reason why the self-sufficiency rate for vegetables assessed in this research is far lower than the 35% assumed the authorities is the remaining data gap regrading vegetables production with large-scale primary agricultural land, which is not covered in the statistical yearbook. The only data source is a statement of DARD of 121 ha vegetable production with primary agriculture in Da Nang, which seems far to low.

However, the analysis demonstrates that the assessed quantities of vegetables generated in secondary urban agriculture significantly contribute to fulfilling local demand.

Table 12 Da Nang self-sufficiency rate for selected food groups based on comparison of different sources of consumption data (*Da Nang statistical yearbook 2016, ** own assessment see 8.2.5)

<table>
<tr><th rowspan="3"></th><th rowspan="2">Current supply</th><th colspan="4">Current demand Da Nang city</th><th colspan="2">Goal provision</th></tr>
<tr><th colspan="2">According to values per capita (FAOSTAT, 2014),</th><th colspan="2">According to values per capita (General Statistics Office in Vietnam, 2016)</th><th colspan="2">According to values per capita based on Vietnamese food security strategy (see 7.2.4)</th></tr>
<tr><th>Supply t/a</th><th>Demand quantities t/a</th><th>Demand coverage</th><th>Demand quantities t/a</th><th>Demand coverage</th><th>Demand quantities t/a</th><th>Demand coverage</th></tr>
<tr><td>Food groups</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fish/shrimps (aquaculture and fishing)*</td><td>34,980</td><td>27,528</td><td><100%</td><td>16,025</td><td><100%</td><td>26,709</td><td><100%</td></tr>
<tr><td>Meat*</td><td>9,690</td><td>59,623</td><td>16%</td><td>23,504</td><td>41%</td><td>40,063</td><td>24%</td></tr>
<tr><td>Rice*</td><td>34,542</td><td>212,717</td><td>16%</td><td>84,400</td><td>41%</td><td>89,029</td><td>39%</td></tr>
<tr><td>Fruits *</td><td>6,503</td><td>67,404</td><td>10%</td><td>12,820</td><td>51%</td><td>44,515</td><td>15%</td></tr>
<tr><td>Starchy roots</td><td>3,145</td><td>12,980</td><td>24%</td><td>n/a</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Vegetables primary production **</td><td>2,081</td><td rowspan="3">136,936</td><td>2%</td><td rowspan="3">55,200</td><td>4%</td><td rowspan="3">106,835</td><td>2%</td></tr>
<tr><td>Vegetables secondary production **</td><td>5,555</td><td>4%</td><td>10%</td><td>5%</td></tr>
<tr><td>Vegetables total**</td><td>7,636</td><td>6%</td><td>14%</td><td>7%</td></tr>
<tr><td>Vegetables, starchy roots and fruits total</td><td>17,284</td><td>217,32</td><td>8%</td><td>68,02</td><td>25%</td><td></td><td>-</td></tr>
</table>

8.5 Summary and conclusion

This chapter explored ways to better assess the spatial manifestation of urban agriculture for subsequent urban spatial planning processes and urban agriculture's role in the urban food system in terms of contributing to the food supply.

Deciphering the spatial expression of diverse practices of urban agriculture and how they have evolved within the voids of the complex urban system is a demanding task which required developing a workflow of different steps that were carried out in recursive feedback lops.

An important initial phase in the workflow was to understand the current data situation, existing knowledge and data gaps. Da Nang's data on food consumption and urban agriculture is patchy. The spatial structures that could potentially be developed as productive green infrastructure that contributes to urban residents' quality of life seem to elude the radar of city administration and urban planning (8.1).

A first approximation to better understand urban agriculture in Da Nang involved gaining insight on the ground and identifying typical patterns of how urban agricultural is practiced and shaped. On this basis and other scholars' approach to establishing typologies (3.3.4), it was possible to categorise and characterise specific typologies. This makes the typologies tangible for further urban planning processes. Differentiating between typologies also allows planners to choose specific assessment procedures individually (8.2). S1) Plots along rather natural open spaces and S2) Urban farming plots could be assessed with relatively high accuracy as they were partly included in the land use geodatabase. It was also possible to trace these typologies rom aerial imagery after collecting samples from field research. In this way, the gathered information was directly integrated into the existing planning reference system of land use geodata. Tracing specific land use types from aerial imagery based on real-life impressions emerged as a suitable tool for creating highly accurate spatial data, and the same was shown with the worldwide OpenStreetMap project (4.5.2.2). While the author carried out this process in this case study, the same process could be used by citizens as a form of 'collective intelligence'. At the time of investigation, the OpenStreetMap of Da Nang was limited, and it still does not cover urban agriculture as last checked in the end of 2022.

Assessing elements that are too small to be identified remotely remains a challenge (i.e., S4) Small-scale urban agriculture and S5 rooftop gardens). The tested mapping procedure firstly served to gain qualitative impressions of how urban agriculture blends into different urban structure types, but it was difficult to amass hard numbers for the actual share of agricultural use. However, using a systemic approach with urban structure typologies referring to density and building height, collecting samples within this frame, upscaling information and adding information regarding vegetation cover presents a potentially fruitful avenue for future research. The conducted mapping presented here provided reference points which, in combination with the remotely sensed vegetation cover and references to residential land use classes, allowed a conservative approximation of the spatial extent of small-scale urban agriculture.

Overall, this work has resulted in the identification, characterisation and quantification of a set of spatial typologies (8.3). The typologies range from large-scale primary production areas mainly operated by professional farmers and covered by official statistics to secondary production types that tend to be more integrated into the urban area. The secondary typologies are smaller in scale and often operated by cooperatives or single citizens. The description and allocation of food production spaces make these spaces recognisable and operationalisable as they can now be subject to urban planning in a differentiated way.

Concluding from the investigations, it was possible to deepen knowledge of the region's food supply rates and thus to add to understanding of Da Nang's urban food system (8.4). Taking satisfactory quantities of food demand per capita into account, local agricultural productivity has limited but notable capacities to supply the growing urban area of Da Nang. A large, previously unquantified proportion of the vegetable supply is generated through secondary urban agriculture.

9 ENVISIONING FUTURE DEVELOPMENTS OF URBAN AGRICULTURE IN THE CONTEXT OF THE URBAN METABOLISM

The assessment of urban agriculture's spatial and systemic dimensions provides a foundation for better deciphering its role in the city's urban metabolism and further exploring potential future developments.

A local reorganisation of resource use modes is one of the most relevant leverages to counteract human-induced negative global implications on the biosphere and simultaneously reinforces the city's resilience. Of all resource flow spheres, the urban food system is among the most powerful drivers of global change (2.3.2). Chapter 3.1 described how the urban metabolism approach aims at modelling complex urban systems' flows – water, energy, food, people and so on as well as related infrastructures – as if the city were an ecosystem. An urban metabolism model can thus be used to reflect existing and potential future setups for better informed urban planning. Urban agriculture can be understood as an urban infrastructure that acts as a catalyst in the cycling of resources, but it has only recently begun to be perceived as part of the urban infrastructure system (3.5.1). There is a general lack of assessing urban agriculture and applying strategic planning at the city level, which means that there is no technical blueprint of how urban food systems (including urban agriculture) should be built or operated.

This chapter investigates how the urban agriculture typologies assessed in Chapter 8 can be further conceptualised in urban metabolism analyses in the Da Nang case. This process first required approaching the main processes as mathematical equations that are substantiated with coherent datasets for the spaces, tonnes of harvest per year per crop group and required irrigation and fertilisers (9.1). The 'Rapid Planning' project made it possible to model and simulate different development scenarios of urban agriculture as part of an integrated infrastructure system based on a series of 'what if' explorative assumptions for an alternative infrastructure setup with PGI as an integral component (9.2). Finally, scenario simulations results are reflected on in Section 9.3.

9.1 Considering urban agriculture in urban metabolism analyses

Sub-section 3.1.3 described urban metabolism research as a broad field that interrogates the complex interrelations between urban and natural systems with divergent scopes and setups. Since the way infrastructures are designed profoundly impacts exchange processes within the urban metabolism (see Figure 5), it is expedient to place infrastructure setup at the centre of structuring an urban metabolism analysis; this approach allows the detection of possible synergies between the infrastructures and ultimately renders the material cycles more circular (3.1.4).

In urban metabolism discourse, urban agriculture is an essential component in closing resource loops because it can utilise treated wastes in the form of nutrients and water generated by the city. It therefore follows that appraising the relationship between entities of urban agriculture and the dimensions of needed inputs in terms of water and fertiliser via the links to the infrastructure sectors of water, sanitation and waste management is crucial. Simultaneously, the relationship between urban agriculture entities and their food supply capacity is of key interest, as outlined in Section 8.4. To obtain this knowledge, entities of urban agriculture need to be analysed in terms of three dimensions: 1) spaces (based on spatial typologies); 2) crop mix (in the form of aggregated groups) and 3) various cultivation methods (see Figure 55). These 'packages' of knowledge related to urban agriculture entities can be integrated into an urban metabolism simulation model and represent simulation blocks.

While in reality, each plot is exposed to different environmental conditions, including soils, light (shading) and different techniques for tending to the plants, defining 'simulation blocks' at the city level presupposes model-like assumptions and simplifications; this includes assigning crop mixes to certain spatial typologies and assuming average yield rates. Defining the simulation blocks and running simulations at the city level serve to tentatively assess orders of magnitude for resource flows, potential supply capacities and potential connections within the urban metabolism.

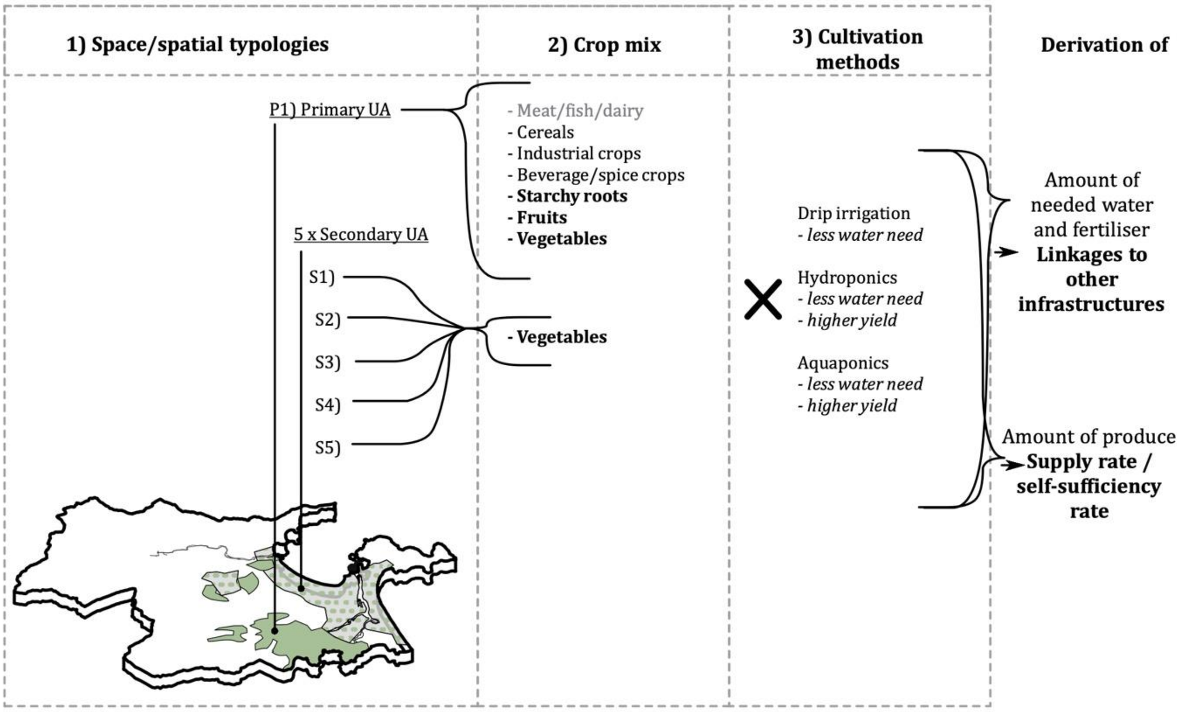


Figure 55 Three dimensions of depicting urban agriculture in urban metabolism analysis

9.1.1 Spaces and crop mix

Assessing and characterising spatial urban agriculture typologies (8.3) enables their individual simulation in a model. Spaces are considered in relation to their productivity for the clustered crop groups. Within this research, the focus is laid on vegetable production for several reasons. Identified urban agriculture typologies are indeed dominantly used for intensive vegetable production, which fits within small urban spaces, requires intensive manual care and generates high revenue. From the point of view of planning a local supply infrastructure, vegetables and fruits are nutritious and perish quickly compared to staple crops, which is why it makes sense to foster short transportation routes within the city region (see 3.2.2.1; 3.2.2.3; 3.2.2.4).

Sub-section 8.2.5 describes how some of the existing statistics are inconsistent, which requires making assumptions to bridge these gaps. The depiction of P1) primary urban agriculture is based on existing and consolidated statistics on crop composition and yields (see Table 11). Regarding secondary urban agriculture, it is assumed that the typologies with smaller units (S2–S5) only produce vegetables. Regarding typology S1) Plots along rather natural open spaces, it is assumed that a third is used to produce vegetables while the rest of the plots consist of meadows or are used for rice cultivation.

As stated in Sub-section 8.2.5, these are model-like simplifications as some of the plots are also equipped with banana orchards or small patches of maize, which technically do not belong to the vegetable food group. However, simplification was necessary to identify city-wide capacities and potentials. Furthermore, crop cultivation schemes are somewhat flexible, and assumptions and related data can always be refined in a more differentiated way for assessments at smaller scales.

9.1.2 Need for irrigation and fertilisers

Assumptions regarding food groups are crucial to estimate orders of magnitude of the required overall input for irrigation and fertilisers and to explore to what extent these needs can be met by redirecting other urban resource flows. These parameters were investigated based on a literature review.

Irrigation

Calculating needed irrigation is a complex matter and depends on a range of locally specific factors. Data from on-site experiences is ideal, if available. If not, indications can be gained from the FAO concept of 'crop water need', which describes the amount of water needed to grow various crops optimally. Crop water need includes water loss through evapotranspiration and indicates the total amount of water needed, which can be met either through rainfall or actual irrigation (FAO et al., 1986).

In Da Nang, some levels of irrigation are required throughout the year, except for at the beginning of the rainy season in October and November, when 40%–50% of annual rainfall appears (see 6.2). Assessing potential irrigation demand is most relevant for secondary urban agriculture typologies integrated into the urban structure and close to the potential source of treated greywater. In the case of Da Nang, local data for irrigation on secondary urban agriculture is documented. Urban farmers in Son Tra District reported actual irrigation amounts of 50 m^3/day in the summer and 20 m^3/day in the winter for vegetable gardens (Quan et al., 2013, p. 20).

Fertilisers

Calculating fertilisers at the city level is an equally complex matter that depends on many factors, including crop type and soil quality. Here again, local values were researched that represent average quantities of used fertiliser. It cannot be reviewed whether the amounts stated are sufficient or beyond the plant's needs, leading to potential eutrophication. It is assumed that quantities are calibrated well for the plants under the local conditions.

Table 13 Calculation of base fertiliser use (obtained directly from DARD in 2016)

Food group	Fertiliser use kg/ha/a							
	Manure		Urea		Phosphate		Potash	
	Average	Range	Average	Range	Average	Range	Average	Range
Cereals	4.000	3.000 – 5.000	114	91-136	60	21-98	59	17-100
Melon, vegetables, chili, flower	6.500	5 - 8 t	97	63 - 130	77	21 - 132	100	30 - 170
Peanut, sesame	3.000	3					60	

9.1.3 Advanced cultivation methods

The resulting spaces and food groups can now be matched with different advanced cultivation methodologies. This work is not written from the perspective of agricultural sciences, and the researched methods and parameters should only be seen as a first attempt to consider this dimension. Overall, three variations on cultivation methods have been included: the use of drip irrigation, hydroponics and aquaponics.

Drip irrigation reduces water need by 50% compared to regular surface irrigation (Gebrehiwot, Gebrewahid, 2016). The advantages of hydroponics and aquaponics include a decreased need for irrigation and plant fertilisers and increased yields. In regular soil-bound cultivation, water is lost through evaporation from the leaves, transpiration from the ground and percolation into the subsoil. In hydroponics systems, water use is reduced to the minimum needed for actual plant growth. A technical paper of the FAO on aquaponics states that the needed water is equivalent to 1%–3% of the total water volume per day (Somerville et al., 2015, p. 29) and that, generally, Aquaponics only uses about 10% of the water used in regular production (Somerville et al., 2015, p. 84). One FAO technical paper on hydroponic systems describes irrigation schemes with added nutrient solutions in which total irrigation amounts fluctuate between 2 and 3.5 litres per m^2 per day (FAO and Marulanda, 1993, p. 87 ff.). Nutrients are added as dissolved solutions, which can be directly tailored to the plants, thus decreasing overall needed input. These solutions can be bought commercially or prepared by the farmers themselves.

The distinguishing feature of aquaponics is its partially closed resource flows as nutrients partly stem from fish manure. The increase in yield for aquaponics is estimated to be around 1.25% compared to the most intense soil-based production, which considering current rates of 17.2 t of vegetables per ha per year in Da Nang would mean an average increase to 20 t/ha/a.

Assumptions on the basic setup, input and output flows of a generic aquaponics system are based on an FAO technical paper (Somerville et al., 2015). The paper describes a setup of a 1,000-litre fish tank connected to 3 m^2 of irrigated media beds, which require specific average fish feed rates and electricity input to maintain certain water flow rates via pumping and water input. The numbers have been converted to hectares – not for the creation of 1-ha sized units but to imagine larger fractions of, for example, rooftop gardens equipped with single aquaponic units that amount to several hectares.

Table 14 Calculation base of advanced cultivation methods

Base			Output	Input		
Aquaponics (Somerville et al., 2015)						
	Size growing bed / crop site in ha	Size fish tank in litres water body L	Average general production rate converted to t/ha/a	Fish feed rate t/ha/a	Irrigation L/ha/day	Electricity water flow rate should be 2000 - litres/h = 2x/h W/h
Fish		3,333,333.33	1.72	602,250,000	30,000[33]	11,665.50
Vegetable	1		20			
hydroponics (FAO and Marulanda, 1993)						
Vegetables	1		20		27,5000[34]	
drip irrigation (Gebrehiwot, Gebrewahid, 2016).						
Vegetables	1		17.2		40,000 in winter and 100,000 in summer[35]	

9.2 Exploring an urban metabolism scenario in which urban agriculture is an integral urban infrastructure

Identifying the typologies of urban agriculture and conceptualising them as simulation blocks facilitates their consideration in urban metabolism simulation models. Such a model was developed in the 'Rapid Planning' project, which made it possible to test scenario simulations with urban agriculture as part of an integrated infrastructure system, which is laid out in the following sub-sections.

9.2.1 Simulation models and scenario setup

The 'Rapid Planning' project (2014–2019) involved developing an urban metabolism model focussed on the nexus between the systems of food, water, energy, waste and wastewater in the case cities. The twofold approach first established MFA models and subsequently advanced simulation models through the 'Rapid Planning Simulator'.[36]

The specific MFA models were established to combine the flow data of energy and materials with process data. As a result, the MFA models depict the material flows from the generation and consumption of energy, water and food and the generation and disposal of waste and wastewater displayed as Sankey diagrams. The work is based on the Umberto NXT LCA® software e!Sankey and Ecoinvent 3 datasets. Processes are defined as simplified black-box models described by selected factors (e.g., efficiency, loss rate). Cross-connecting flows between the infrastructure sectors were identified and potential interlinkages qualified and quantified (Franke et al., 2020). MFA models helped to harmonise and visualise existing datasets and were in part preparatory work for developing the simulation models.

Unlike the MFA, the simulator attempts to integrate the spatial dimension and time series. Models were built with the dynamic simulation environment SIMBA#, a software that emerged from the modelling of physical, biological and chemical processes of wastewater and water systems. Like the MFA models, the simulation models consider the entire urban infrastructure sector, which meant that extensions for waste, energy and food had to be developed within the project (Robleto et al., 2020a).

Moreover, the simulation model aims at integrating the spatial dimension by locating simulation modules representing specific processes, such as water treatment plants, and representing end users consumption of resources and generation of wastes based on a 'spatial unit' concept. In this way, certain distances

[33] The source states a range of 1%–3%, with 2% being equivalent to 66.667 L/ha/day, which seemed too high. Value has been adjusted in the light of the hydroponics technical paper and knowledge of current actual irrigation need in Da Nang

[34] Average of 2 to 3,5 litres per m² per day

[35] Half of current irrigation needs

[36] The 'Rapid Planning' simulator was developed by IFAK (Institute for Automation and Communication). MFA models were developed by project partner IFEU (Institute for Energy and Environmental Research) Heidelberg gGmbH. Building both the simulation models and the MFA was a collaborative process in the consortium.

between process modules and spatial units can be analysed and configured. Spatial units can be individually tailored depending on the availability of existing data and can represent any scale, from a single building to a block or the whole city region. In the case of Da Nang, spatial units refer to districts; their projected population development; and adherent values for average consumption of water, food and energy and generation of wastewater and solid waste. Adherent values also regard levels of connectivity to certain infrastructures, such as different sanitation concepts (e.g., grey, black, brownwater and urine separation) and decentralised water sources for non-potable uses (e.g., rainwater harvesting; (Robleto et al., 2020a, in preparation).

9.2.2 Scenario setup

During the 'Rapid Planning' project, a 'baseline scenario' was established depicting the current state of the urban metabolism with its basic resource flows and infrastructure setup of water, energy, food, wastewater and solid waste. As noted, Da Nang's urban metabolism can be considered a 'once-through' system in which nutrient and water cycles are managed inefficiently, despite water and nutrients being increasingly scarce resources.

To depict potential future developments, two scenarios for the time horizon of 2030 were defined. The 'reference scenario 2030' is based on existing plans and the goals of major planning frameworks (see 7.5.1) and specific sectoral plans. An alternative 'trans-sectoral scenario 2030' explored an alternative future development in which infrastructure planning is carried out in a more integrative manner based on a more comprehensive understanding of the relations and constellations of the urban metabolism. The setup aims to identify linkages and potential synergies between the infrastructure sectors, thereby tightening resource cycles and improving overall resource management. Experimenting with the trans-sectoral scenario was done in an exploratory manner based on 'what if' assumptions for alternative infrastructure development formulated with local stakeholders during a workshop.

9.2.2.1 'What if' assumptions for urban agriculture as an integrated PGI

Assessing previously unnoticed food production spaces in Da Nang and classifying them as typologies was a prerequisite to their consideration for further planning purposes. The distinct typologies can now be conveyed through their immanent features. Typologies can therefore be understood as differentiated elements of Da Nang's urban landscape. Potential future developments and angles for further qualification of these typologies were indicated in Section 8.3. The following paragraphs present a potential setup for a 'what if' trans-sectoral scenario.

A key feature of the alternative scenario setup is that urban agriculture is maintained as an integral urban infrastructure despite the pressure of urbanisation as it develops within new urban extension areas. A rough notion of the amount of needed water for irrigation and fertilisers at the city level can be gauged by running through the what-if scenario, which helps to calibrate the system and identify the extent to which these needs can be satisfied by directing excess urban resources such as fertilisers from organic wastes and greywater into urban agriculture.

The status quo of existing urban agriculture typologies and general trends

As urban agriculture is not on the agenda of urban nor infrastructural planning, most of the medium-scale agricultural structures on public ground, on currently vacant lots or in natural areas along the rivers and meadows are assumed to be removed as urban development progresses. Though some of the informal habits on private grounds may continue and may be practiced in urban extension areas, discussions in the scenario workshops confirmed that P1 primary agricultural areas are decreasing rapidly due to urbanisation. There will be a concentration of agricultural areas in the West of Hoa Vang District, as seen in the Urban Masterplan (see Figure 24). The general tenor for future development corresponded to the contents of the approved Urban Master Plan (see 7.2.4 and 7.3.2.3). Production is to shift towards high-quality and safe products and from staple crops towards fresh crops (fruits and vegetables) to supply local consumers.

Assumptions on maintaining and qualifying existing urban agriculture typologies

Type S1) Plots along rather natural open spaces

Vast areas of the S1 typology are characterised as either meadows or riparian flood plains, which mitigate urban flooding by infiltrating surplus rainwater and providing retention spaces. Hence, preserving these areas would bring a multitude of benefits. The trans-sectoral scenario assumes that the typology's areas will not be urbanised and will instead be further qualified.

Type S2) Urban farming plots

The locally specific urban farming plots represent community garden clusters integrated into mostly dense urban areas that otherwise have an almost total lack of green spaces. Maintaining and further qualifying these spaces is a unique opportunity to improve green space supply within the immediate residential environment. However, while the city permits intermediate use of these spaces, current land use plans make it clear that in the long run, the city intends to develop the plots as they are often already classified as 'residential' (see Figure 41 and Figure 42).

Hence, it is assumed that 80% of the existing urban farming plots are maintained and further qualified as recreational community gardens. Like allotments, the areas need to be accessible and enjoyable for the public by integrating paths and recreational spaces as a form of placemaking. The unit's productive character represents a valuable asset in terms of small-scale resource loops and fostering the local food growing and preparation culture. Moreover, offering long-term uses would enable farmers to improve their infrastructure systems in terms of direly needed irrigation systems. The scenario assumes that 25% of plots are equipped with drip irrigation and another 25% install hydroponics.

Type S3) Construction / fallow land

The amount of construction land is constantly changing. With more than 2,500 ha, there is currently an enormous amount of construction land (7.5.1). It is uncertain whether urban growth processes will continue after 2030 given that population growth is levelling off. Overall, it can be assumed that this vast amount of construction land is a temporary phenomenon. Hence, the scenario definition made no assumptions regarding the future prevalence of construction land or its share of use for urban agriculture within the time horizon of 2030.

Type S4) Small-scale urban agriculture

Approximately 3% of residential areas are currently used for small-scale agriculture. Presumably, citizens will continue to grow vegetables in their front gardens and suitable public spaces. This type of agriculture should be further encouraged. In future urban development, both the reference and the trans-sectoral scenario assume that knowledge of cultivation techniques and the enthusiasm to grow food will be passed on to the next generations and maintained.

Type S5) Rooftop gardens

The total amount of space dedicated to rooftop gardens remains unknown, but rooftops gardens are popular in Da Nang and are often built on the shophouse buildings. The number of existing shophouses was investigated through remote sensing, which resulted in an estimate of 2,300 ha of total rooftop space. Currently, planned areas are dominated by shophouses, which will lead to about 6,000 ha of rooftop space in 2030, or about 5,800 ha in the trans-sectoral scenario. To run the base and reference scenario, it is assumed that about 1% (23 ha) of rooftop spaces are used for growing food. With the growing popularity of rooftop gardens, it can be assumed that 2% (46 ha) of rooftops may be used in this capacity in the future. The trans-sectoral scenario explores a setup of 5% (116 ha) rooftop usage, which could be reached through additional incentives.

Assumptions on integrating urban agriculture typologies into urban extension areas 2030

Type S2) Urban farming plots

As observed in recently built structures in urban extension areas, some blocks remain unbuilt and are designed as parks (see 7.4.1). About 5% of new extension areas are designated for this type of green spaces for a total of about 275 ha. In the trans-sectoral scenario, these parks will serve not only as hubs for sports and recreation but also as multifunctional green spaces forming nodes for decentralised local infrastructure systems, similar to existing urban farming plots. A total of 20% (49 ha) of these multifunctional parks are assumed for agricultural use. This assumption only applies to 'regular urban extension areas', as the 'agricultural urban neighbourhood' typology features private gardens at each house.

Type S4) Small-scale urban agriculture

Practices of small-scale urban agriculture are present in established urban structures and newly developed extension areas. Consequently, it is also assumed that 3% of residential area is used for urban agriculture, resulting in a total of 164 ha.

Type S5) Rooftop gardens

The trans-sectoral scenario explores a setup of 7% of rooftop usage, which would yield about 243 ha of rooftop gardens. It also assumes that part of these rooftop gardens are set up as hydroponic or aquaponic systems.

Assumptions on the 'agricultural urban neighbourhood'

The notion of the 'agricultural urban neighbourhood' in which 'the community can grow and supply food for themselves' was proposed by a participant in the scenario definition workshop (DARD representative at the 'Rapid Planning' scenario workshop on 27 June 2018 in Da Nang) and became a typology for further planning processes (see Figure 56). To correspond to Da Nang's Urban Masterplan, the idea of the 'agricultural urban neighbourhood' was translated into an altered design of the typical residential development scheme, which is based on single-family rowhouses (see 7.4.1). While the strong emphasis on the single-family building typology can be questioned in terms of overexploiting land (see 7.5.1), the new urban agriculture typology took advantage of the general layout and equipped each block with a green 'spine', allowing each resident of the single houses to tend to a small backyard (about 40 m^2) and grow the vegetables, fruits and herbs that are otherwise often cramped into Styrofoam boxes along the sidewalk or grown on temporarily vacant plots (see 7.4.4). The design 'translation' served to derive altered urban design proportions with decreased space for buildings. While the average new settlements consist of 60% buildings, 35% roads and 5% parks, in the altered version, the share of space for buildings accounts for 45%, with 15% used for the green spine of productive patches, whereas the single building plot's size remains the same. There could be different approaches to adapting the layout, such as decreasing the construction plot size and increasing the number of stories from an average of two to three or more as up to five are allowed (see 7.4.1).

Creating greater varieties of design solutions requires more interdisciplinary design processes involving architects and urban planners. The setup derived here served to create a general idea for a possible layout and to quantify urban agriculture spaces for the scenario simulation.

The new typology was projected onto the map to generate its total size in an additional step (Figure 57). For this purpose, the designated urban extension areas that have not been developed yet were scanned, and those located at current agricultural land were identified. The trans-sectoral scenario 2030 assumes that some of these areas – about 514 ha of 4,117 ha – are developed according to the idea of the 'agricultural urban neighbourhood'. The total size of their green spines amounts to 77 ha. The scenario assumes that an average of 70% of this land is used for growing food. This way, a total of 54 ha of currently fertile agricultural land is preserved in the form of productive private gardens.

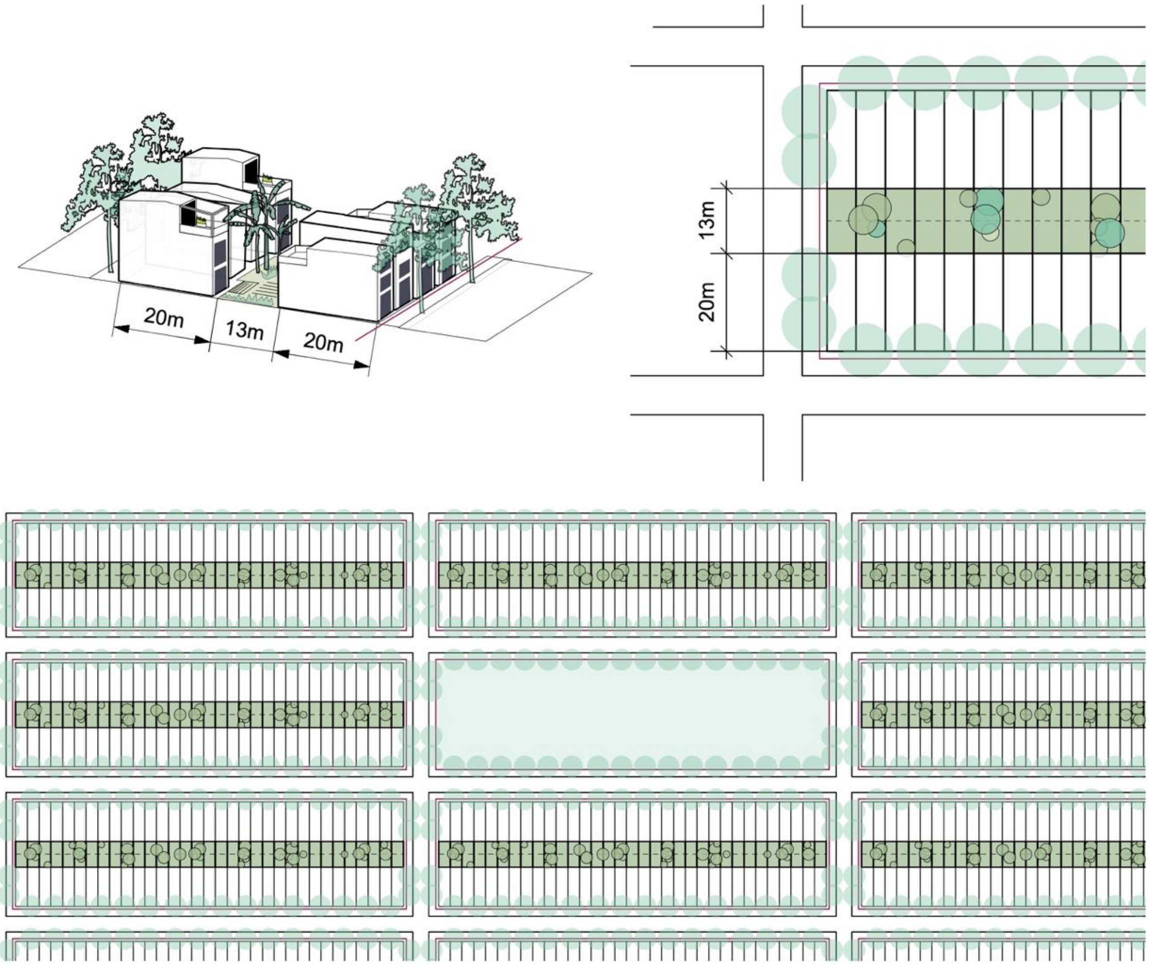
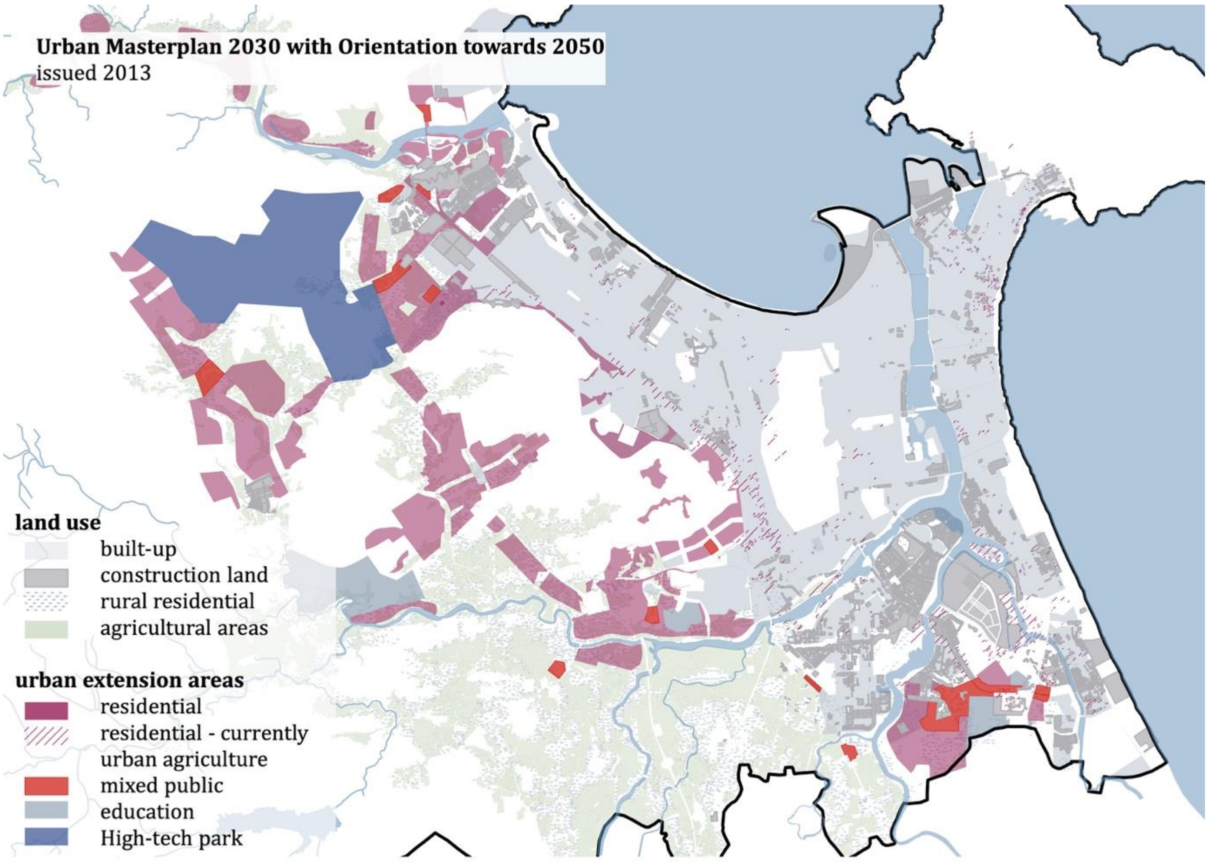


Figure 56 Depiction of potential generalised layout of the 'agricultural urban neighbourhood', an alteration of currently dominant layout (see Figure 27)



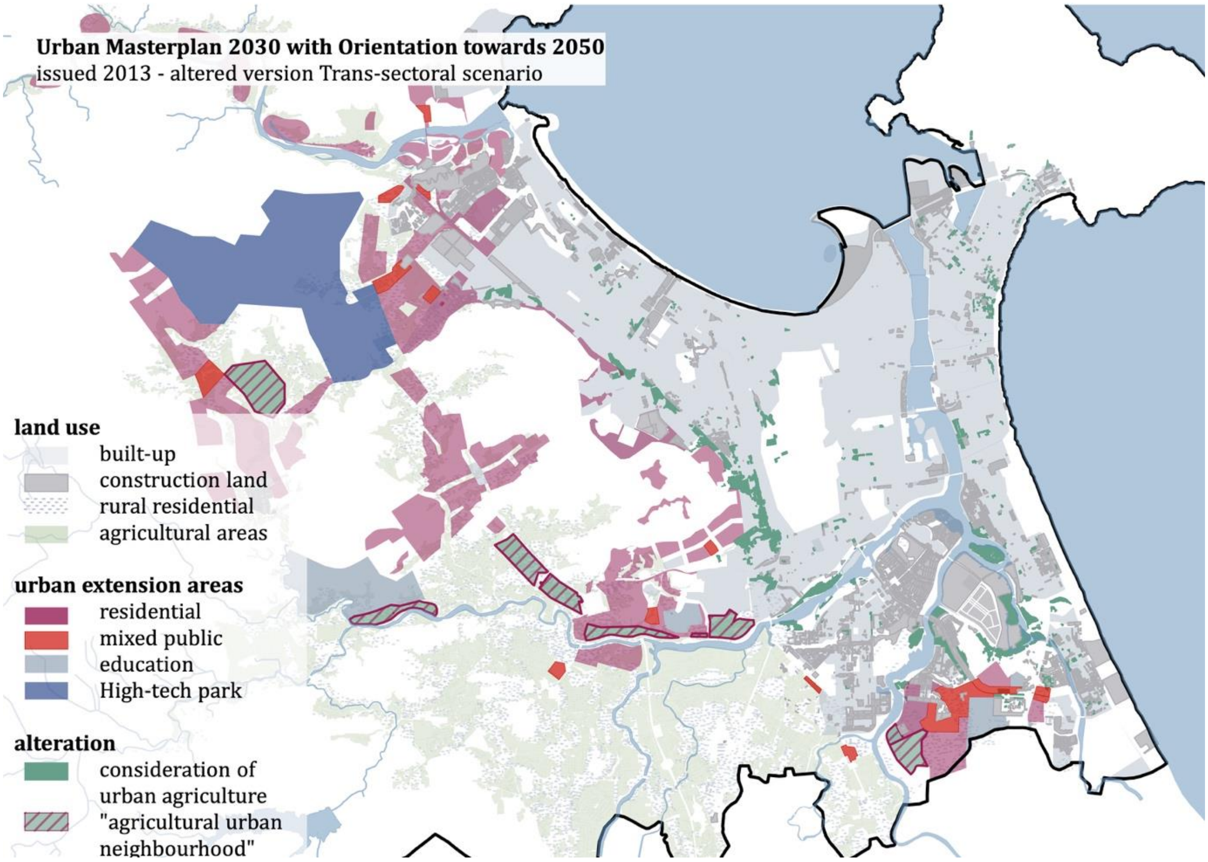


Figure 57 Original Urban Masterplan and altered version per the trans-sectoral scenario

9.2.2.2 'What if' assumptions regarding links to water and waste infrastructure

Conceiving generated urban wastes as potential resources and increasing the share of their recovery can improve the urban metabolism (see 3.1.4). This attitude requires a radical change in how large, pipe-based infrastructure systems of wastewater are designed and installed and the way solid wastes are collected and separated in each household and enterprise.

Water and wastewater systems

Currently, only some of the households in Da Nang are connected to the drainage system, ranging from 20% to 65%, and there is an urgent need to renovate and adapt existing structures. Most households are equipped with separate septic tanks that pre-treat greywater before it enters the drainage systems. The tanks are often not properly accessible. Some of them are never extracted, and settled black water constantly seeps into the system (Mohr, 2014). In most of the urban area, the drainage systems are built as a combined system, collecting both pre-treated wastewater from septic tanks and rainwater that periodically leads to an overflow in the case of heavy rains and urban flooding, resulting in heavy pollution. Separating the different water flows would be an alternative development to what is currently planned. The city's goals to treat 100% of the wastewater and reuse 25% by 2020 was ambitious. The city intends to continue relying on slightly improved septic tanks in each household and extending the capacities of the existing combined sewer system (communicated during scenario workshop on 27 June 2018). Authorities expect an increase in water consumption per capita which, in combination with rapid population growth, will lead to a quadrupling of water consumption from about 170,000 to roughly 650,000 l/day.

The alternative scenario assumes that 30% of the new buildings are equipped with a system, in which wastewater is separated and that greywater is obtained as a valuable resource for irrigation and toilet flushing. This reduces the amount of wastewater needing treatment from about 250,000 l/day in the reference scenario to about 200,000 l/day in the trans-sectoral scenario. Moreover, the research team assumed a more minor increase in water use per capita – 120 l instead of 176 l/capita/day. The reuse of greywater for toilet flushing in 30% of new settlements further reduces freshwater need to 100 l/capita/day. Given that water shortages occur during dry season (6.2.3), increasing water sufficiency and efficiency is inevitable.

Solid waste

Managing the rapidly increasing amount of solid waste is a challenge in Da Nang. Waste management currently relies on a single large landfill with limited capacity and ongoing pollution issues. The city intended to collect 100% and recycle 70% of generated waste by 2020, which would first require the separation of waste at source. To achieve waste separation, new financing mechanisms must be implemented. Separated bins for organic waste, recyclables, and residual waste as well as adherent collection vehicles and a sorting facility must be installed. The city currently plans to build one central composting facility and an incineration plant for wastes that cannot be recycled or composted. The trans-sectoral scenario setup mainly upholds these planning directions but assumes three instead of one composting facilities. This way, transportation routes are reduced, fostering a more decentralised approach and easing the distribution of resulting fertilisers to local PGI elements.

9.2.2.3 Overview of assumptions

The following table is an overview of assumptions regarding the different urban agriculture typologies based on the three dimensions of space, food groups and cultivation technique in relation to needed inputs and resulting output of produce in the three scenarios.

Table 15 Data table behind scenario simulation of urban agriculture

Key parameter	Status quo	Assumption of possible future development 2030	
	(2014-2018)	Reference Scenario	RP Trans-sectoral scenario
Primary agriculture - various produce			
Area	ha	ha	ha
Total area	**8,225**	**3,000**	**3,000**
Aquaculture	470	400	400
Cereals	5,757	2,000*	1,500*
Fruits	307	200*	400*
Vegetables	121	400	300*
Vegetables drip irrigation	*0*	*0*	*500**
Starchy roots	*503*	*0*	0

Beverage/ spice crop	151	0	0
Industrial crops	917	0	0
Yield	t/ha/a	t/ha/a	t/ha/a
Aquaculture	1,72	1,72	1,72
Cereals	6	6	6
Fruits	19,7	19,7	19,7
Vegetables	17.2	17.2	17.2
Starchy roots	6.3	6.3	6.3
Beverage/ spice crop	2	2	2
Industrial crops	16	16	16
Total output	t/a	t/a	t/a
Aquaculture	808	688	688
Cereals	34,542	12,000	9,000*
Fruits	6,503	3,940	5,910*
Vegetables	2,081	6,880	13,760*
Starchy roots	3,145	0	0
Beverage/ spice crop	302	0	0
Industrial crops	14.672	0	0
Secondary agriculture – focus vegetable production			
Area	ha	ha	ha
Total area	**323**	**401**	**1,027**
S1) Plots along rather natural open spaces			
Total ha	**120**	**0**	**360***
S2) Urban farming plots			
total ha	**80**	**0**	**64**
S2.1 Soil bound ha	80	0	32
S2.2 Hydroponic/aquaponics	*0*	*0*	*16*
S2.3 Drip irrigation	*0*	*0*	*16*
S2x) Urban farming plots in urban extension areas - multifunctional green spaces, drip irrigation	***0***	***0***	***49***
S3) Construction/fallow land	0	0	0
S4) Small-scale urban agriculture			
[Generalized] total average share of small scale urban agriculture in residential urban structure	3%	3%	3%
[Generalized] total area of small scale urban agriculture ha	**100**	**280**	**269**
of which are in existing urban structure		105	105
of which are in urban extension area		174	164
S5) Rooftop gardens*			
total ha	**23**	**121**	**359**
Total rooftop area regular buildings ha	2.317	6.061	5.789
of which are in existing urban structure		2.317	2.317
S5.1 Soil bound%	1%*	2%	4%*
S5.1 Soil bound ha	23	46	93
S5.3 Hydroponics/aquaponics%	*0*	*0*	*1%**
S5.3 Hydroponics/aquaponic	*0*	*0*	*23*
of which are in urban extension area		3.744	3.472
S5.1 Soil bound%		2%	5%*
S5.1 Soil bound ha		75	174
S5.3 Hydroponics/aquaponics%	*0*	*0*	*2%**
S5.3 Hydroponics/aquaponics	*0*	*0*	*69*
S6) Agricultural urban neighbourhood* drip irrigation	***0***	***0***	***54****
Yield	t/ha/a	t/ha/a	t/ha/a
Soil bound plots	17,2	17,2	17,2
Hydroponics/aquaponics	20	20	20
Area relation	ha	ha	ha
Total area soil bound	323	401	1,159
Total area hydroponics/aquaponics	0	0	108
Total output	t/a	t/a	t/a
Vegetables from regular soil bound production	5,555	6,897	19,934
Vegetables from aquaponics or hydroponics	0	0	2,160
Vegetables total			22,094
Total output primary and secondary vegetables t/a			
Vegetables total	7,636	13,777	35,854

Need irrigation in urban extension area, potential for greywater usage (excluding S1 and S5[37])	L/ha/day	L/ha/day	L/ha/day
Soil bound regular			
Winter (oct-april)	80.000	80.000	80.000
Summer (may-sept)	200.000	200.000	200.000
Advanced technologies – drip irrigation			
Winter (jan-april)	40.000	40.000	40.000
Summer (may-sept)	100.000	100.000	100.000
Area relation	ha	ha	ha
Total area of secondary urban agriculture integrated in urban extension area, soil-bound regular production	-	174	164
Total area of secondary urban agriculture integrated in urban extension area, drip irrigation	-	0	103
Total amount of needed water	L/day	L/day	L/day
Winter (jan-april)	-	13,920,000	17,240,000
Summer (may-sept)	-	34,800,000	43,100,000
Potential use of compost max. 13,33 t/a	t/a	t/a	t/a
Total primary agriculture	103,374	39,990	39,990
Total secondary agriculture	4,306	5,345	15,449

9.2.3 Results of scenario simulation

9.2.3.1 Food sufficiency rate

With a business-as-usual scenario and the continuing disappearance of urban agriculture, in 2030 the remaining gardens on private ground could generate about 6,900 tonnes of vegetables per year.

The alternative scenario simulation shows that maintaining part of the existing urban agriculture and considering urban agriculture as part of the infrastructure in future neighbourhoods would considerably contribute to covering the need for fresh produce. The alternative setup would result in a total supply of about 22,094 t/a of vegetables from secondary production alone. Moreover, substantial amounts of fresh produce could be generated by dedicating primary agricultural land to growing vegetables and fruits at the expense of less rice production area as rice is a staple crop that can more easily be stored and transported over longer distances. Altogether, the self-sufficiency rate of vegetables could be raised to 13% and that of fruits kept at 7%, although demand will continue to increase with the growing population and available space will continue to decrease.

Based on the goal quantities for food group per citizen from the national food strategy (100 kg of rice, 120 kg of vegetables, 50 kg of fruits per year), the following demand cover rates can be achieved within the region.

Table 16 Vegetable demand cover rates in the different scenarios

Key parameter	**Status quo**		**Assumption of possible future development 2030**			
	(2014-2018)		**Reference Scenario**		**RP Trans-sectoral scenario**	
	Demand	Supply	Demand	Supply	Demand	Supply
Rice	89,029	34,542	2,300,000	12,000	2,300,000	9,000
Rice sufficiency rate	35.5%*		5.2%		3.9%	
Fruits	44,515	6,503	115,000	3,940	115,000	7,880
Fruits sufficiency rate	**14.6%**		**3.4%**		**6.9%**	
Vegetables primary production, quantities	106,835	2,081	276,000	6,880	276,000	13,760
Vegetables secondary production, quantities		5,555		6,897		22,094
total		7,636		13,777		35,854
Vegetables sufficiency rate	**7.1%**		**5.0%**		**13.0%**	

[37] S1 has easy access to water from river filtration; rooftops will likely be watered with collected rainwater and tap water

9.2.3.2 Increased consistency of the urban metabolism through links with the water and waste infrastructure

The scenario simulation created a better understanding of the magnitude of nutrient and water flows and indicates possibilities for increasing the consistency of the urban metabolism.

Separating and valorising wastewater resources would result in 35,374 l greywater per day, of which portions could be distributed to nearby secondary agricultural areas. Greywater is available as a constant stream all year round, largely independent of climatic conditions. This setup would contribute to strengthening resilience with regard to expected future climatic changes. It is assumed that about 65% (22,993 l) of the generated greywater would remain after treatment in constructed wetlands, 35% of which would become sludge. Assuming that 20% of the population within the newly built areas use greywater for toilet flushing requires 5,822 l/day, thus 17,171 l/day remain for irrigation. That amount of water could cover the irrigation demand of ground-level agricultural space developed within the urban extension areas (267 ha) to 100% during winter and to approximately 40% during summer. It seems key that greywater treatment is carried out in a decentralised manner, possibly on the block level, which would allow direct distribution of irrigation water to adjacent production units. Greywater treatment can be done in either a low-tech manner based on constructed wetlands, which requires large territories and is difficult to adapt to the block level, or through advanced membrane filtration systems that require less space.

In both scenarios, the aim is to better recycle solid waste and especially to use the high proportions of organic material for the production of compost.[38] The amount of generated compost would far exceed the needs of agricultural areas within the city region and could be exported to more distant production areas, potentially as a co-load of the food distribution network. Compost could supplement the use of other fertilisers within the city region to an extent. The scenario simulation calculated the replacement rates for primary urban agriculture. Through the use of compost, the demand for urea could be covered by about 40%, while almost the total demand for phosphate can be covered (94%) as well as for potash (100%). For a more holistic analysis of Da Nang's nutrient cycles, further analyses on the regional scale are required that also consider the amounts of manure generated through livestock and the potential of phosphate recovery from the wastewater system in relation to nutrient demand beyond the city region.

9.2.3.3 Environmental impact assessment

An environmental impact assessment is crucial to evaluating a potential infrastructure setup and enables management of environmental impact by identifying 'emission hotspots' (Franke and Zeitz, 2020, p. 12). In this way, human-induced planetary alterations can be better considered in the planning process alongside established economic and social criteria. The assessment can then guide choices for more sustainable technologies.

First steps toward an environmental impact assessment were developed as part of the project based on simplified life cycle assessments (LCAs) and life cycle impact assessments (LCIAs). The analysis focused on certain technologies and processes of Da Nang's current and potential future infrastructure setup, their total resource demand and the selected indicators' global warming potential and eutrophication potential (Franke and Zeitz, 2020, pp. 3–4). Many of the indicators are based on the international Ecoinvent Database, meaning that they are not necessarily coherent with local conditions (Robleto et al., 2020b, p. 24).

Based on the selected processes and the assigned criteria, both future scenarios (reference and trans-sectoral) indicate less eutrophication potential, mainly because of proper handling of solid waste. Improved waste management also positively correlates with a reduction in greenhouse gas emissions (Franke and Zeitz, 2020, pp. 15–16). A fundamental but so far unquantified environmental threat lies in the current handling of septic tanks, which are rarely correctly emptied and constantly diffuse into the system. Moreover, the combined sewer for both allegedly pre-treated wastewater from septic tanks and rainwater frequently collapses in the event of heavy rains and spills excess water into the sea before treatment (6.3.1.2). This enormous eutrophication potential could not be included in the calculation because the extent and frequency of the phenomena of eutrophication is unpredictable.

[38] Calculating the extent to which compost can substitute for fertilisers in the form of manure, urea, phosphate and potash is a complex process that was carried out by the 'Rapid Planning' team's experts based on the nutrient composition (N, P, K, P205 and K20) project led by IFAK (Institute for Automation and Communication), IFEU (Institut für Energie- und Umweltforschung Heidelberg), AT-Verband and TU Berlin

Assessment of the environmental impact could not be done. Currently, the simulation blocks representing production are assigned with a certain eutrophication potential. A high share of urban agriculture in the city would then result in a poor balance sheet, which is misleading. In reality, one of the decisive factors for eutrophication is that cultivation is carried out without excessive fertilisation. According to the principles of green infrastructure, cultivation techniques must be sustainable.

Whether production takes place in the urban region or outside of it is irrelevant to determining eutrophication potential. Two other factors are decisive here: 'food miles', or the distance a food item travels before it arrives at the place of consumption, and diet composition. In this respect, fruit and vegetables produced in the city's vicinity would stand out positive because lower CO_2 equivalents arise due to limited logistics and cooling (see 3.2.2.3). Highly perishable products are also less likely to be wasted along the value chain with shorter transportation routes, thus increasing the sufficiency of the system. In addition, the proportion of meat in the diet is crucial as its production is much more energy-intensive. To analyse the food system's environmental impact in a meaningful and systematic way, the 'food miles' of imports need to be assigned with relevant values. Moreover, typical local consumption patterns need to be analysed rather than local production patterns.

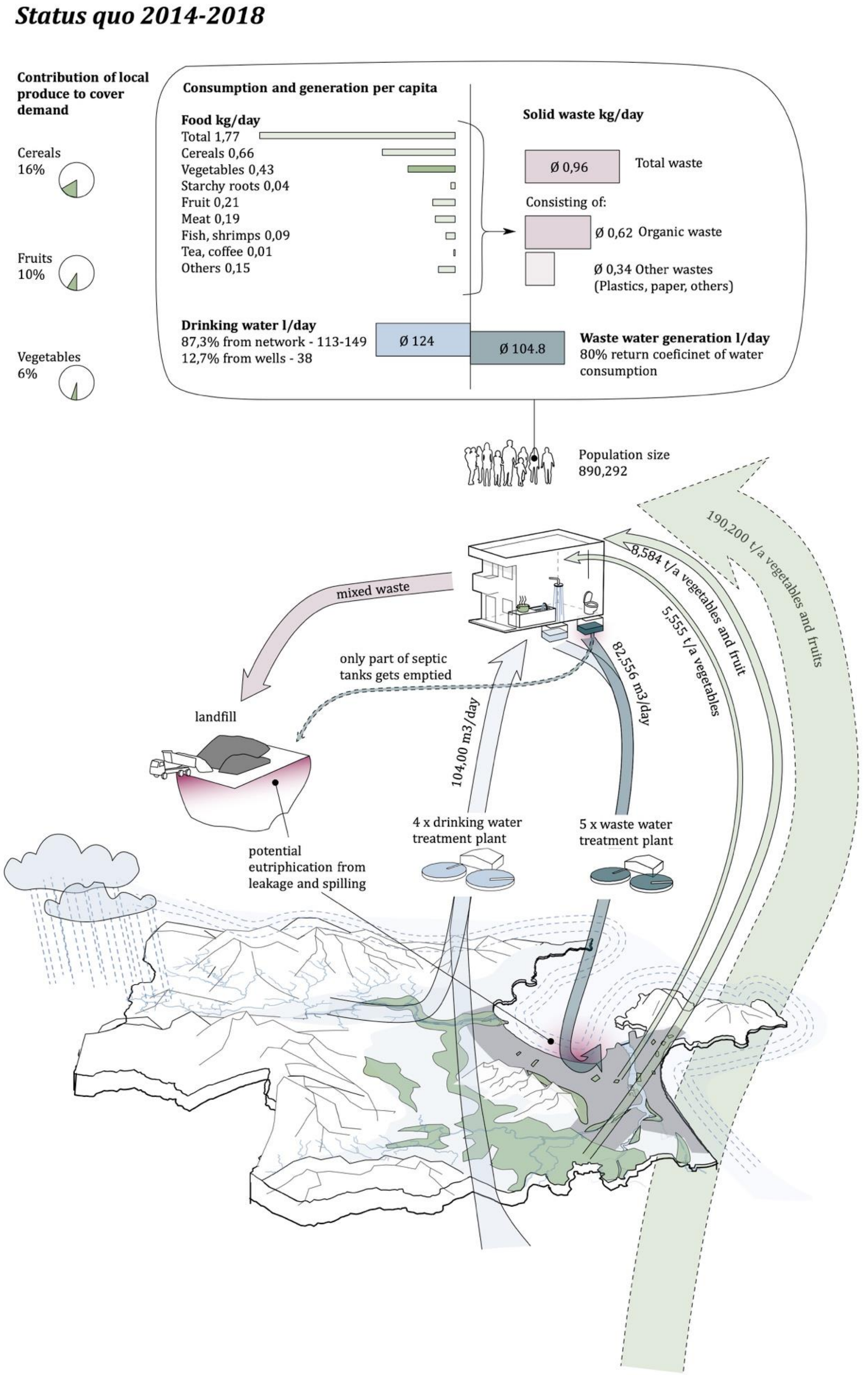


Figure 58 Baseline setup of the status quo, data from 2014–2018; based on 'Rapid Planning' Scenario Simulation (Final report - Kasper et al., 2019; Deliverable report D 6-3-/6.4 - Lindschulte et al., 2019b; and Deliverable report D-6.6. Robleto et al., 2020b). New visualisation within this dissertation, data on food and urban agriculture revised

Reference scenario 2030

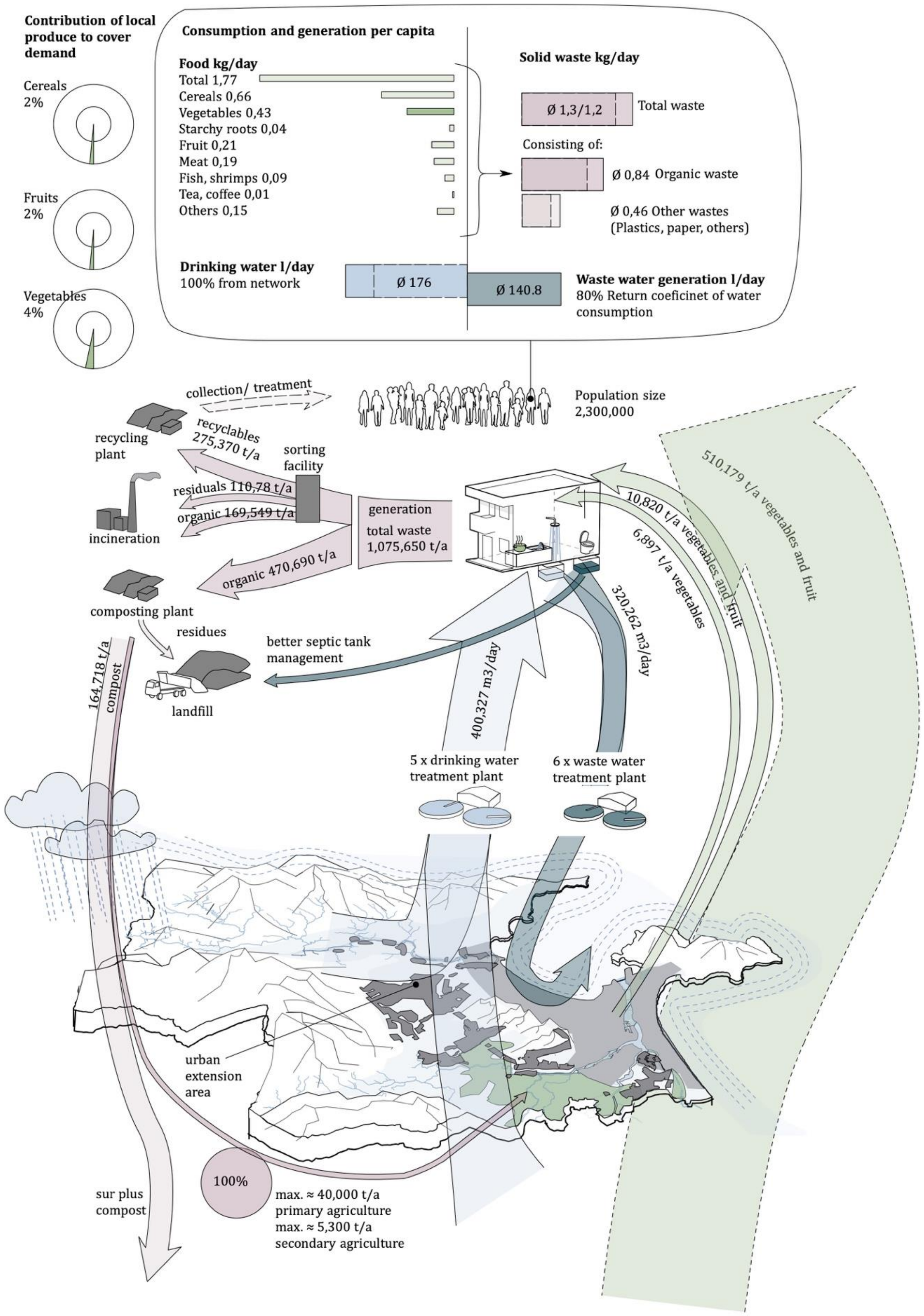


Figure 59 Reference scenario 2030 as expressed in existing Masterplans and scenario workshops; based on ‘Rapid Planning’ Scenario (Final report - Kasper et al., 2019; Deliverable report D 6-3-/6.4 - Lindschulte et al., 2019b; and Deliverable report D-6.6. Robleto et al., 2020b). New visualisation within this dissertation, data on food and urban agriculture revised

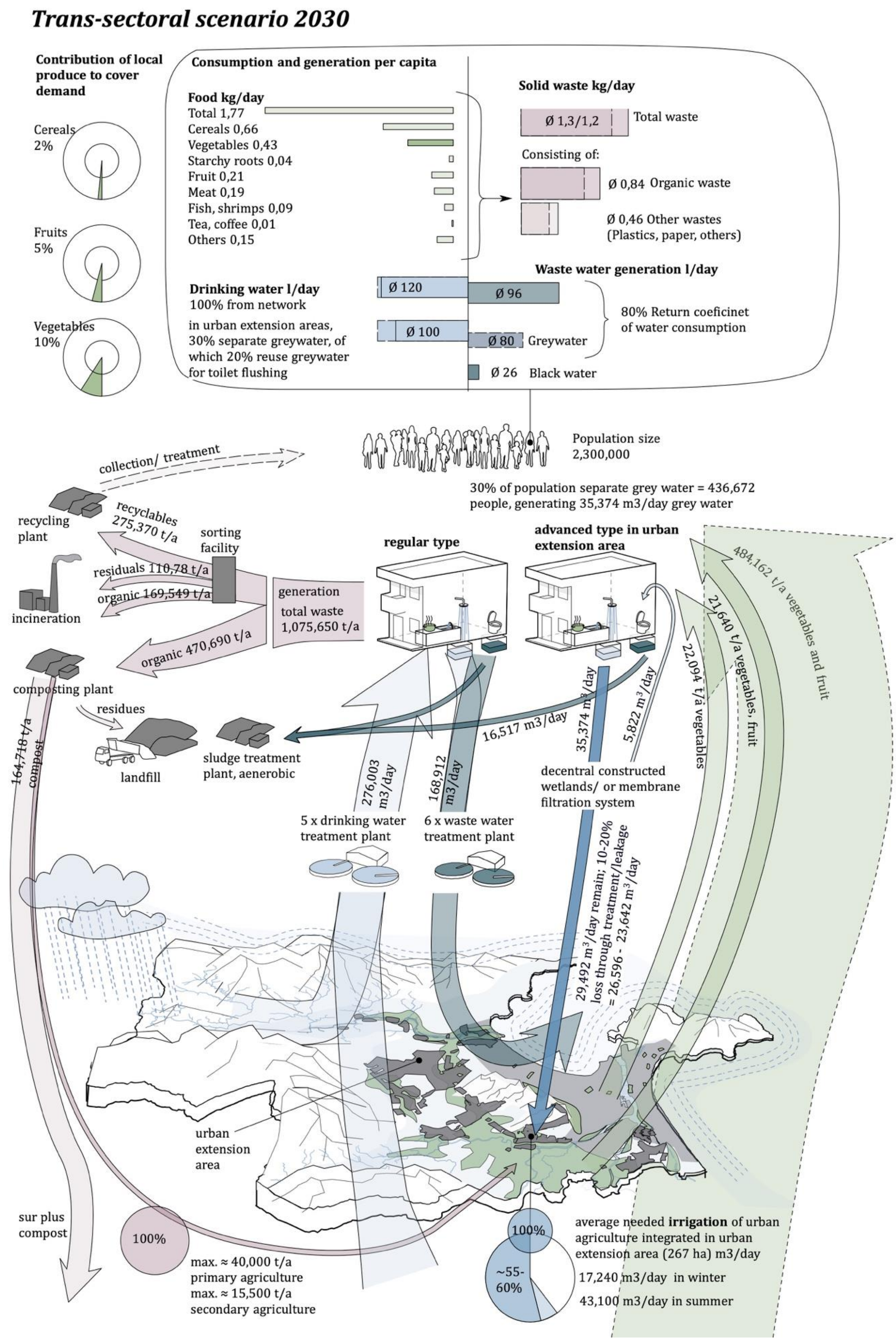


Figure 60 Trans-sectoral scenario 2030, 'what if' assumptions of 'Rapid Planning' Consortium and participants of 2018 scenario workshop. Based on 'Rapid Planning' Scenario Simulation (Final report - Kasper et al., 2019; Deliverable report D 6-3-/6.4 - Lindschulte et al., 2019b; and Deliverable report D-6.6. Robleto et al., 2020b). New visualisation within this dissertation, data on food and urban agriculture and irrigation revised

9.3 Summary and conclusion

Chapter 9 conceptualised the links of the urban agriculture units to the larger realm of the urban metabolism and creating a basis for exploratory scenarios. This required researching and assigning values for needed irrigation and fertilisation to the units of urban agriculture as well as researching advanced cultivation methods and their influence on productivity and needed inputs (9.1). As a result, the units of urban agriculture were characterised as simulation blocks that can be integrated into dynamic simulation models to explore potential future constellations and to establish links to other infrastructures, particularly those related to water and waste (9.2).

The 'Rapid Planning' project made a first attempt to model the city's urban metabolism in terms of its water, waste, energy and food infrastructure, which allowed testing of the integration of urban agriculture. Thus, the simulator is breaking new ground, though it is still at the beginning of the development, and there is potential for further refinements. The simulator exceeds the black box model (see Box 2) as imports and influxes from outside the system, understood as the administrative boundaries of the city region, are considered in addition to interlinkages between the sectors (Schütze, 2019).

Within the project's framework of outlining a reference scenario for 2030 according to existing plans and an alternative scenario for 2030, it was possible to explore different benchmarks for urban agriculture and tentatively assess orders of magnitude for resource flows, potential supply capacities and potential connections within the urban metabolism. With the combined measures of strengthening the identified types of secondary urban agriculture and partly shifting to vegetable production in primary peri-urban agricultural sites, the self-sufficiency rate of vegetables could be increased to 13% despite a sharp increase in population size. In contrast, with a business-as-usual development, the self-sufficiency rate would drop to 5%. Using these scenarios, a new observation and planning perspective was opened linking future urban development layouts to the supply rates generated by urban agriculture.

Envisioning future urban development areas in which just 20% of households separate greywater would significantly and steadily contribute to the irrigation demand of close-by urban agriculture, with 40% demand coverage in summer and 100% in winter. Moreover, collecting and recycling organic wastes as fertilisers would far exceed the needs of urban agriculture within the whole city region. The model and scenario simulation outlined the processes at the city level; to derive useful planning parameters for individual new development areas, it is necessary to adjust the analysis scale and to further concretise the assumed values, check their interdependencies and draw site-specific conclusions. If the utilisation of greywater for urban agriculture is to be pursued further, this needs to be thought through and planned in an integrative manner at the neighbourhood and subsequently block levels. At the same time, a more profound analysis of the nutrient cycles requires widening the scale to the regional level as well as including manure from livestock and phosphate recovery from the wastewater system.

Within the project's scenario simulation, first steps were made to outline the environmental impact of the setup based on simplified LCAs and LCIAs with the international Ecoinvent Database. Reliable statements can only be derived if the relevant metabolic relationships can be sufficiently translated into model assumptions and corresponding datasets. It becomes apparent that it may be necessary to switch between the scale levels. For example, the possible environmental impact of eutrophication needs to be seen in connection with the regional nutrient cycle.

Apart from hard numbers about supply rates and environmental impact, the infrastructure setup and related flows are relevant in ways that cannot be quantified. Qualitative properties include the extent to which created infrastructures influence residents' everyday lives, whether the structures are controlled and maintained centrally or jointly and how much issues of distributive justice are raised and negotiated transparently. It is also essential to consider the extent to which the infrastructures shape the cityscape from an aesthetic perspective. Are they visible and thus tangible or invisible, and to what extent does their physical appearance contribute to societal understanding of Da Nang's urban metabolism? These questions can be raised only to a limited extent at the city level but must guide further planning processes.

10 ENVISIONING A GREEN INFRASTRUCTURE SYSTEM WITH PGI

Based on the assessment and visualisation of existing urban agriculture (Chapter 8), it was possible to explore the relationship between urban agriculture typologies and selected components of the city's urban metabolism by developing 'urban agriculture simulation blocks' (Chapter 9); this then allowed exploration of a potential future development with different benchmarks for urban agriculture typologies as part of the existing urban structure and part of future urban development sites. The analysis was based on model assumptions regarding spaces and processes. In this sense, the simulation can support decision-making for general planning directions. Further steps of spatial planning would be required to further elicit the potential of urban agriculture and create spatial design proposals. Hence, this chapter illustrates which further steps could be taken to anchor urban agriculture as a PGI in the Da Nang region and its urban metabolism in the case of Da Nang.

This thesis pursues the idea that an active planning of urban agriculture in connection with the city's green space system marks the turning point at which single informal and incidental elements of urban agriculture become a PGI. In this sense, the green infrastructure approach is used to *envision* PGI and solidify potential development goals from the urban metabolism analysis and scenario simulation. Accordingly, the chapter draws on the definition of PGI laid out in Section 0 describing PGI as a specific element of green infrastructure with its unifying key principles (see 3.5.1).

Developing a green infrastructure network with an emphasis on PGI is a demanding task that would require multi-level political support, a far-reaching participation process with a wide range of stakeholders and the work of a larger interdisciplinary team. This dimension of planning cannot be accomplished in the framework of this dissertation. However, to illustrate how the results from the previous analyses of urban agriculture can be implemented, potential further steps are outlined to gain an understanding of the overall green space realm and draft visions for potential PGI layouts.

The chapter begins with a reflection on the starting conditions for green space planning in Da Nang and the potential suitability of a PGI approach (10.1). Potential sites for building a green infrastructure network are then outlined (10.2). Based on this, a vision for a PGI spatial framework and potential functions is drafted (10.3). Furthermore, references to existing plans and planning processes are illustrated (10.4), followed by a summary and conclusion (10.5).

10.1 Starting conditions in Da Nang

This dissertation understands PGI as elements of urban agriculture that are assessed and operationalised as part of a strategically planned green infrastructure network while also considering PGI's role within the urban food system and urban metabolism. Chapter 3.5.3 described how green infrastructure was created as an approach to spatial planning, emerging from planning discourses in the US and Europe. To date, green infrastructure is rarely applied in Asia (see Box 5). However, the internationally declared SDGs, to which Vietnam is particularly committed, coincide with major principles of green infrastructure.

Until recently, Da Nang's urban green spaces merely consisted of private gardens within residential structures; horticultural decorations as part of monuments; religious or administrative sites; and remaining unbuilt areas such as the beaches, mountains, and regularly flooded riversides. Recently, public parks have been implemented in urban extension areas. However, urban densification and expansion of urban areas are based on a complete land turnover (7.5.2), leading to a progressive reduction and fragmentation of green space structures.

Green space planning has only recently become part of the urban development agenda in Vietnam and Da Nang, but it is highly emphasised through ambitious planning parameters for supplying citizens with recreational green spaces (7.5.3).

With rapid urbanisation and increasing awareness of sustainability, the negotiation processes for urban green spaces are currently taking place. The implementation of the highly ambitious goals for the creation of larger green space systems are a demanding task. Similar to the fast-growing cities of the Global North in the 20th century, the shape and size of green space systems in relation to built-up areas and their related economic aspects are now imprinted into the urban structure.

Green infrastructure could be a suitable instrument for Da Nang to realise its ambitions for the implementation of green spaces and to contribute to its goal for sustainable urban development.

10.2 Identifying potential sites

The ever-extending urban metabolism into the 'global hinterland' decouples spheres of complex urban systems and makes it difficult to lend a sense of agency to planning decisions made on the local scale

(4.6.1). The analysis of potential sites for the urban food system and green infrastructure emphasise the region, its continuous landscape areas and its potential. Even if the planning authority only affects one's own territory, connections between the regions can be identified, and common goals can be set at the interregional level.

Creating a green infrastructure network requires a spatial analysis of potentially suitable sites with 'green baseline elements' and 'grey sites offering potential' (Hansen et al., 2017a, pp. 11–12). Green base elements reflect the existing spectrum of green spaces and can be clustered into four types of nature in urban areas[39]:

- (semi-)natural landscapes such as river courses, wetlands, near-natural forests;
- (agri-)cultural areas of arable land and grasslands, silvicultural landscapes;
- designed green spaces such as parks, allotments, cemeteries;
- novel urban ecosystems, such as succession sites of 'urban wilderness'.

Grey sites address any other urban surface such as building rooftops, streets, or conventional infrastructures that can be upgraded by applying the planning principle of green-grey integration.

These universal categories illustrate a bandwidth of spaces that helps to create an overview at the city scale. The assignment is fluid, and elements can be assigned to multiple categories. The categories reach beyond the 'classic' fields of action of landscape architects by considering the realm of farming and forestry and by considering the qualities of spontaneous development of nature in urban areas. Considering the entirety of green spaces is crucial to identifying possibilities for improving the connectedness of the elements and defining specific development goals for individual sites, in addition to recognising their potential multifunctional uses (see Figure 10).

10.2.1 Description of Da Nang's green space system

In Da Nang, the qualities of *(semi-)natural landscapes* – or remnants of near-natural landscapes – are closely linked to its diverse topography (Figure 61). Some relatively natural areas are the forested highlands. The more elevated and the more difficult to reach an area is, the less intensive use it has been put to (6.2.3.1). Forested areas of Da Nang's hinterland and the Son Tra peninsula are home to many species, including some primates (6.2.3.2). For classic landscape connectivity approaches to enhancing biodiversity (3.5.3.2), these areas can be considered as hubs of the system. As Da Nang lies in the estuary of a large river basin, its whole social-ecological system is characterised by the water regime, which is also a key feature of prevalent (agri-)cultural landscapes (6.2.2).

Within the larger perspective of the entire green space system, agrarian landscapes are prevalent in Da Nang's mid- and lowlands, forming an extensive belt around urbanised areas. River valleys of productive greenways reach into urbanised areas, creating important links between intra- and peri-urban green spaces. A second green belt is formed by a narrow valley of remaining grasslands and acres between urbanising areas and the Thon Dai La and Hoa Phat foothills (S2 plots along natural green spaces).

Patches of intra-urban agriculture are integrated into densely built-up areas and often represent the only open space elements. There is a smooth transition to the categories of *designed green spaces and urban wilderness.* For example, S2) Urban farming plots, which resemble allotments or community gardens plots, are often enclosed by a spontaneous hedge of shrubs and grasses. Other types of novel urban ecosystems are prevalent in unused riversides and vacant lots.

A high share of street trees and rooftops gardens is another key feature of Da Nang's urban green spaces. In addition, Da Nang's most prominent open green spaces are the beaches and riversides and an increasing share of urban parks within new development areas.

10.2.2 Spatial manifestation of Da Nang' green space system

Based on the categories of (semi-)natural, (agri-)cultural, designed green spaces and novel urban ecosystems, a map of the green space elements can be collated. Figure 61 's depiction exceeds the administrative boundaries to reflect the larger landscape context.

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[39] Simplified characterisation of urban vegetation led to the description of four types of urban 'nature': nature of the first kind – original natural landscape; nature of the second kind – agricultural and silvicultural cultural landscape; nature of the third kind – symbolic nature of horticultural facilities; nature of the fourth kind – specifically urban-industrial nature, also described as novel urban ecosystems (Kowarik, 2018, p. 337, 1992)

The groundwork for outlining the extent of the (agri-)cultural and the (semi-)natural landscapes at the regional scale was done over the course of the general description of Da Nang's ecological system, in which existing cartography of the topography and land use were taken as a base (6.2). The basic plans included the city's land use plan, the Urban Masterplan 2030, the Integrated Development Strategy for Da Nang (DaCRISS) by JICA, and scientific literature including the results from the Land Use and Climate Change Interactions Project in Central Vietnam (LUCCi). Complementary aerial imagery was used (RapidEye scene 2015).

The reflection of 'designed green spaces and urban wilderness' examines characteristics of intra-urban green space elements. Elements of urban agriculture significantly contribute to the overall amount of existing green space. The plan section also displays the planned green spaces as depicted in the Urban Masterplan 2030. Some of the planned green space corridors overlap with existing urban agriculture structures, particularly with S1) Plots along rather natural open spaces, indicating that maintaining and further developing these spaces as a PGI could contribute to implementing the Urban Masterplan.

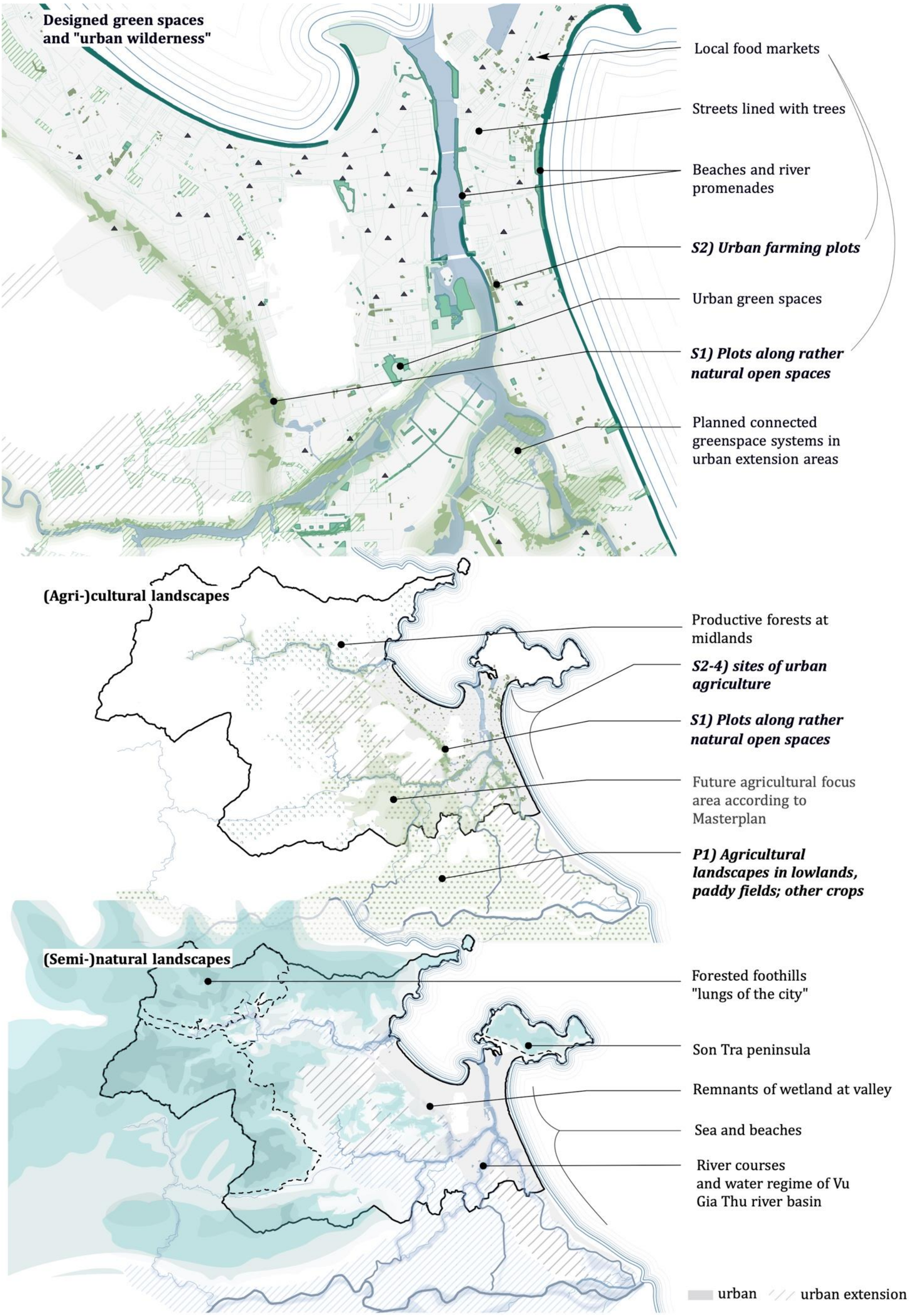

Figure 61 Da Nang's elements to be considered for a green infrastructure approach. Based on cartography of land use plan, the Urban Masterplan 2030, aerial imagery, DaCRISS and LUCCi

10.3 Drafting visions for a green infrastructure system with emphasis on PGI

10.3.1 Determining development goals for green infrastructure and PGI

Green infrastructure is a strategic spatial planning approach that creates a systemic understanding of the existing inventory of green spaces and their 'infrastructure' functioning (see 3.5.3). Enhancing these multiple functions is a key principle of green infrastructure planning and requires weighing and setting specific development goals in view of site-specific qualities as well as existing urban challenges.

As derived from the analysis of overarching planning frameworks (7.5.1, Figure 33), among the most pressing urban challenges and related planning goals green infrastructure could contribute to are the following points.

- **Climate change adaptation**
    - Vietnam is one of the countries most impacted by climate change due to sea-level rise, coastal flooding and prolonged droughts (IPCC et al. 2018, 231). Da Nang is more and more affected by seasonal weather extremes, with low water supply during droughts and heavy cloudbursts during rainy seasons resulting in urban flooding (see 6.2.3; 6.3.2.2).
    - Climate change adaptation is anchored at the national level (SEDP, National Strategy for Climate Change (7.2) and city level (SEDP, Green Growth Strategy, Urban Masterplan 2030; 7.3).

    → *Conserving important green spaces (low-lying plains and river basins as retention spaces) and expanding urban green infrastructure are vital to climate change adaptation. With its 'sponge function', green infrastructure can regulate the regional water cycle by absorbing water during the rainy season, rebalancing groundwater levels and mitigating urban heat island effects. Incorporating PGI expands the total extent of green infrastructure and its effectiveness (see 3.5.2). Moreover, intelligent irrigation schemes in connection with the city's water and waste water systems by combining green and grey infrastructures can contribute to more sustainable and resilient water cycles (see 3.1.4).*

- **Improving food security and sustainable land use**
    - Until the Doi Moi reform in the 1980s, Vietnamese citizens suffered from food shortages and widespread malnutrition. Even today, low-income groups consume less vegetables compared to high-income groups (6.3.1.2).
    - Ensuring access to adequate food for 100% of the population is therefore a specific goal of Vietnam's National Food Security Strategy. It further formulates specific provision goals for food groups, including vegetables per capita (7.2.4).
    - At the global scale, urbanisation is consuming valuable fertile land. It has been estimated that Vietnam will lose up to 10% of its total cropland, which accounts for 15.9% of production loss as near-urban cropland is more productive (1.41 times more productive than the regional average; (Bren d'Amour et al., 2016).
    - Hence, the national guideline for the Urban Masterplan enforces sustainable urban development and the fostering of urban rural links (7.2.2), and former plans to urbanise agricultural areas in the fertile low-lying flood plains have been discarded (Figure 24).

    → *The strategy to improve food security can be further solidified at the regional level. Strengthening PGI elements in connection with retail structure improves the accessibility of food within the region, particularly fresh produce (see 3.2.2.3 and 3.2.2.4).*

- **Promoting biodiversity**
    - The Annamite Mountain Range at the foothills of Da Nang is an area of global conservation priority of critical biological importance
    - Better implementing measures for biodiversity conservation, particularly in the forests, is declared in the local SEDP (7.3.1), which is also reflected in Da Nang's Urban Masterplan (7.3.2.2).

    → *The green infrastructure approach aims at increasing habitat connectivity and can help to steer urbanisation to preserve and upgrade spatially and functionally coherent green spaces (see 3.5.3.2). Green infrastructure also promotes sustainable land use via multifunctionality. This entails gearing existing agricultural land uses towards sustainable cultivation practices and developing them as structurally rich habitats. The incorporation of PGI can limit the expansion of agricultural land use and thus preserve valuable near-natural remnants.*

- **Improving the supply of recreational green spaces for residents and tourists**
    - Increasing the share of urban green spaces is anchored at the national level, with the National Green Growth Strategy suggesting that local Urban Masterplans should prioritise the allocation of land for green spaces (7.2.3). Da Nang's SEDP formulated the concrete objective of increasing the green space supply from 3–4m^2 per person to 9–10m^2 per person (7.3.1) in the Urban Masterplan (7.3.2.4).

    → *The green infrastructure approach is a direct tool for realising these goals. Incorporating PGI in the form of community gardens significantly expands the search space to create and cultivate intra-urban green infrastructure and corresponds to the idea of strengthening typical local open space qualities.*

10.3.2 Spatialised draft vision for a green infrastructure network with an emphasis on PGI

Considerations of how green infrastructure and PGI can contribute to addressing existing urban challenges must be organised into a map to orient the development foci for the different sites (Figure 62).

Visualising spatial constellations emphasises that Da Nang's major river systems play a vital role in networking the various open spaces, as underlined in existing plans (e.g., the Urban Masterplan). In contrast, the qualities of the valley that fringes the dense urban structures and foothills of the Thon Dai La and Hoa Phat Mountains seem unrecognised. The valley is currently characterised as a near-natural pasture and arable landscape that could be strengthened as a green belt. Due to its location behind settlement areas, it has potential to mitigate urban flooding and at the same time represents an open space that is easily accessible to many residents.

As became apparent in the depiction of intra-urban designed green spaces (Figure 61), the densely built-up area of Da Nang has few green spaces. The preservation and qualification of existing urban agriculture elements represents an opportunity to perpetuate a grid of different urban green infrastructure elements.

The draft vision also considers urban extension, which offers the possibility to integrate connected multifunctional green infrastructure systems early on.

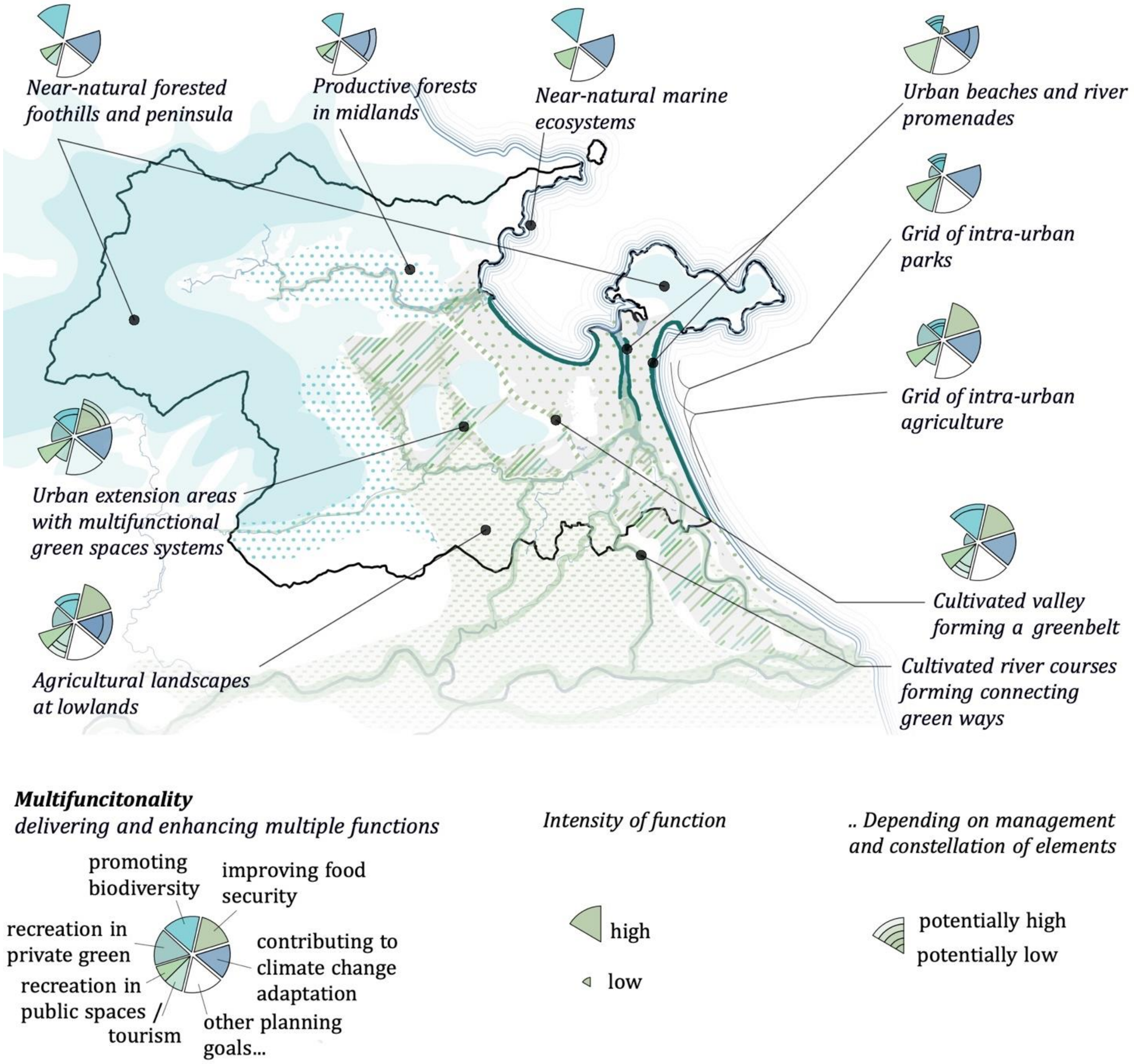

Figure 62 Draft vision for a green infrastructure network with emphasis on PGI. Spatial framework and potential functions

10.3.3 From model assumptions to spatial planning: Further envisioning PGI

The green infrastructure approach serves as a framework for envisioning PGI and concretising potential development goals based on the urban metabolism analysis and exemplary scenario simulation (Chapter 9). The 'alternative' scenario 2030 experimented with different benchmarks for the identified elements of urban agriculture. This included assumptions for the development of urban agriculture within existing neighbourhoods as well as ideas for integrating urban agriculture as a PGI into new development sites (see 9.2.2.1).

As laid out in this work's definition of PGI (4.1), this thesis adopted the GREEN SURGE research project's principles (Hansen et al., 2017b) (see 4.4.1).

- Green-grey integration – combining green and grey infrastructures
- Connectivity – creating green space networks
- Multifunctionality – delivering and enhancing multiple functions and services
- Social inclusion – collaborative and participatory planning

In the following, these principles are used as an orientation to exemplary draft visions for two selected sites.

10.3.3.1 Concretising assumptions on maintaining and qualifying existing urban agriculture typologies – draft vision riverside

As stated, Da Nang's river system is a functional and spatial anchor structure for strengthening the region's green infrastructure system. In the course of the scenario simulation, it was assumed that the identified typology S1) Plots along rather natural open spaces consisting of meadows in lowlands and riparian flood plains would not only be excluded from being built up but also further qualified.

The following graphic exemplarily illustrates how the corridors along the riversides could be developed as multifunctional and productive open spaces. Highlighting their full potential are important in the weighing process of urban development. Given identified challenges and urban planning goals, the following functions could be strengthened:

- *Climate change adaptation*
    - Strengthening the green corridors alongside the rivers and securing retention capacity mitigates risks of high floods. This crucial function can be complemented with additional usages.
- *Improving food security and sustainable land use*
    - Maintaining and further developing agricultural land use of the fertile soils along the rivers with immediate access to irrigation sources critically contributes to the food supply of the city region.
- *Promoting biodiversity*
    - A specific quality of corridors is their connective character for wildlife. Further studies are required to better understand the occurrence and needs of local species and how to increase habitat structures.
- *Improving the supply of recreational green spaces for residents and tourists*
    - Developing the riversides to represent attractive recreation areas adds another functional layer by integrating pathways to explore the mix of cultivated and near-natural landscapes and by interlocking these with urban green space structures. This way, the productive river could form the 'front' of the new neighbourhood and create a sense of identity.

The following draft highlights which functions are most relevant for further strengthening at the site according to the challenges and the multifunctionality principle. The drafted layout also incorporates the connectivity principle by creating networks of different green spaces.

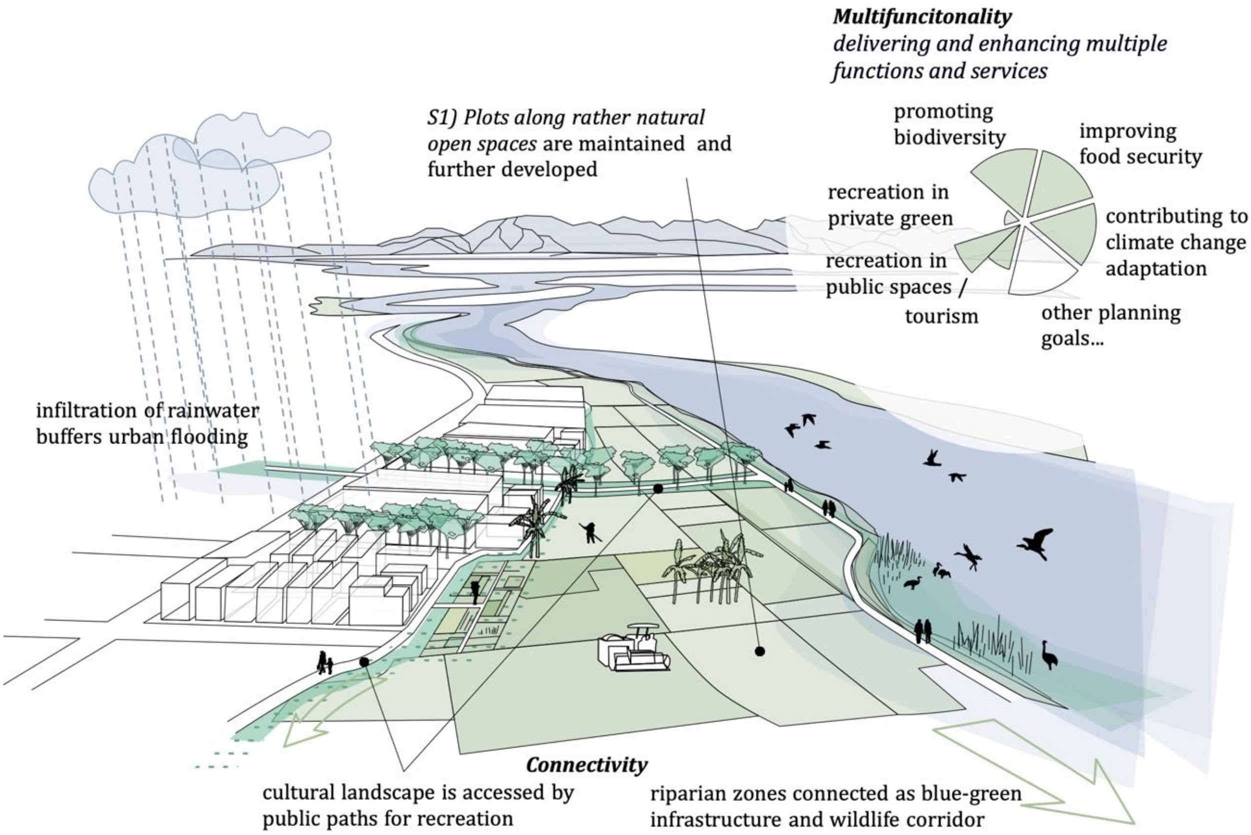

Figure 63 Exemplary visualisation of green infrastructure elements

10.3.3.2 Integrating urban agriculture typologies into urban extension areas 2030: Exemplified draft of 'agricultural urban neighbourhood'

In the scenario simulation, approximate benchmarks were assumed for each of the identified typologies of urban agriculture, which are closely linked to existing development plans. This included translating the idea of an '*agricultural urban neighbourhood*', as expressed in the scenario workshop, into an adapted urban layout (Figure 52). The idea is to equip the planned shophouses with a small backyard-garden of about 40 m^2 each, which would form continuous 'green spines' in the neighbourhood. Another basic adaptation to optimise urban metabolism is assuming that in part of the new development sites, greywater will be collected and used for irrigation.

Particularly for the new development sites, in-depth design thinking processes are required to further explore how a Da Nang urban neighbourhood with a green infrastructure system and PGI could look.

The following sketch takes a step in this direction (Figure 64). Drawing on the identified challenges and urban planning goals, the green infrastructure system with PGI could be designed to contribute to

- *Climate change adaptation*
  - Creating a decentral grid of a blue-green infrastructures mitigates urban flooding. Green yards and rooftops can provide retention space and cooling through evaporation, thus mitigating urban heat island effects. Using greywater for irrigation would distinctly increase resilience towards the dry season as a certain amount of water would be available year around.
- *Improving food security and sustainable land use*
  - Creating neighbourhoods with a PGI would foster local food culture, maintain and transfer knowledge and provide opportunities for a self-supply of fresh produce.
- *Promoting biodiversity*
  - Not much is known about species diversity in Vietnamese urban settlement structures, but establishing a certain diversity of connected vegetation structures likely has a positive impact on habitability and, in turn, creates opportunities to experience urban nature 'at the doorstep'.
- *Improving the supply of recreational green spaces for residents*
  - Creating a grid of connected green spaces in the neighbourhood consisting of private backyard gardens as well as public parks would ensure access to recreational green areas.

Again, according to the multifunctionality principle, the following draft highlights which functions are most relevant for further strengthening at the site. Connectivity is indicated by the network character of the drafted green space system. Further concretisation of the interaction between PGI and the water infrastructure expresses the principle of 'green grey integration'.

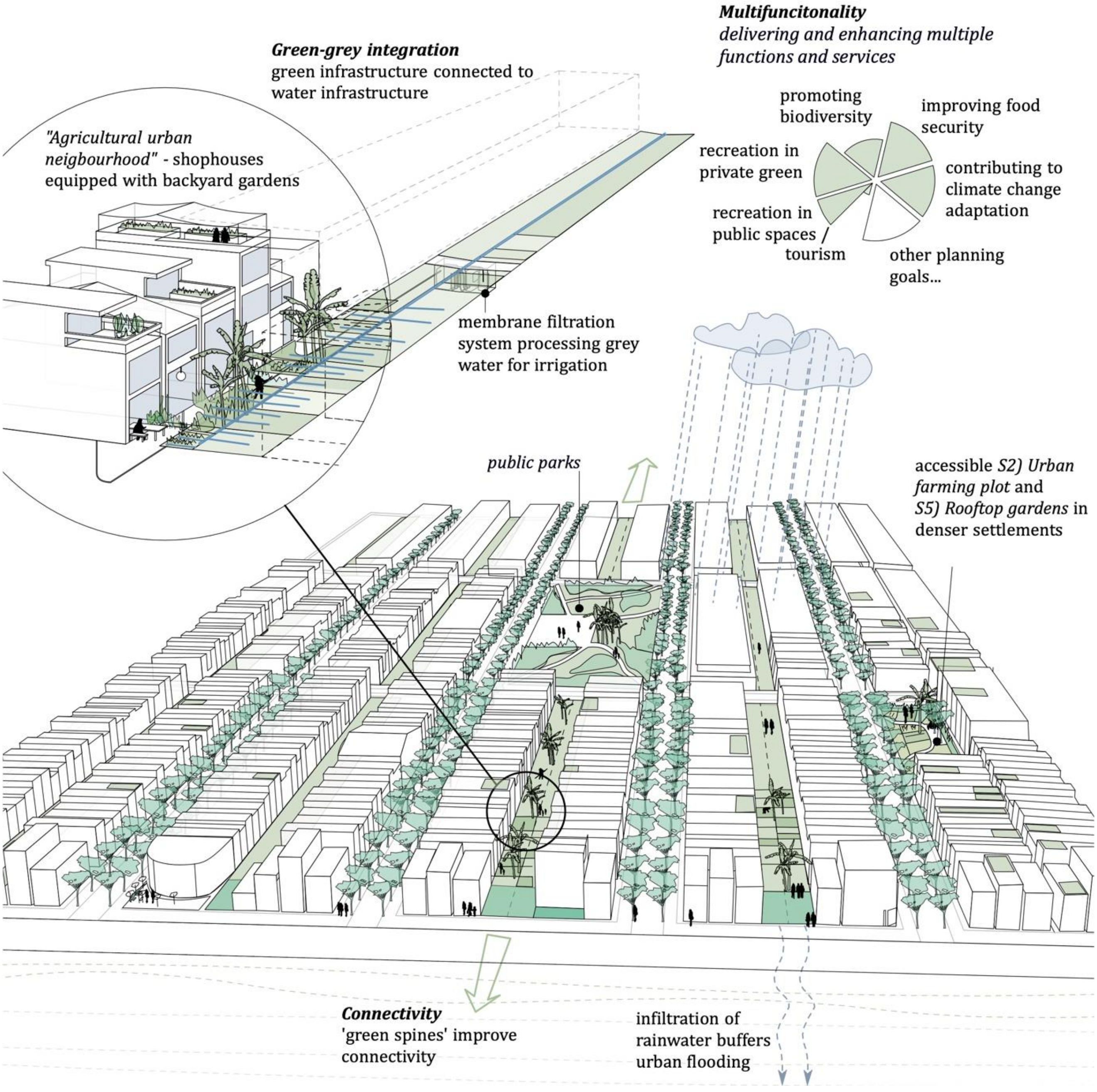

Figure 64 Exemplary visualisation of green infrastructure elements to be developed in urban extension areas based on the modification of local building principles – see Figure 56 Depiction of potential generalised layout of the 'agricultural urban neighbourhood', an alteration of currently dominant layout (see Figure 27)

10.4 Potential further planning steps

The previous subchapters outlined how urban agriculture could be envisioned as a PGI and part of a green infrastructure system while linking to existing planning goals and everyday practices of urban agriculture. Further pursuing this concept would require political will and public support as the design of public spaces and infrastructures is something that permeates various spheres of socio-ecological urban systems.

The outlined draft vision for a PGI and green infrastructure in Da Nang is a first approximation. While the qualities and potentials of urban agriculture have been analysed in some detail, the realm of other green spaces would need to be subject to more profound analyses and planning. Moreover, concretising ideas for integrated infrastructure planning for an optimised urban metabolism would require further interdisciplinary planning processes.

The following outlines potential steps which would be required if Vietnam and Da Nang decided to further pursue green infrastructure and PGI planning.

10.4.1 Links to existing planning frameworks

Among the steps towards an implementation of PGI is creating a supporting planning framework, engaging in more participatory processes and ultimately facilitating citizens' informal urban agriculture practices. There are several levels of action to consider.

National level

As Vietnam's planning system is significantly determined by central agencies defining planning directions (7.1), the idea of a green infrastructure network would need support at the national level; this would also benefit setting inter-regional goals. Links with pressing challenges and goals regarding climate change adaptation, improving food security, promoting biodiversity and improving the supply of recreational green spaces were laid out throughout this chapter. Against this background, green infrastructure and PGI can be understood as an approach to implementing the national goals of the overarching Green Growth Strategy (7.2.3) and SEDP (7.1.2), which again reflect internationally declared goals of sustainable development (7.2.1).

At the national level, the emphasis on PGI corresponds to the National Food Security Strategy (7.2.4) and would support implementation at the city region level. However, changes would need to be made regarding land use restrictions for rice to permit cultivation of non-staple crops such as fruits and vegetables.

Ultimately, Urban Masterplans represent the key instruments for directing spatial development. Their national objective states that development should allocate public land 'to expand the area of green space and water in urban areas' and 'encourage communities, enterprises and households to mobilise resources for the greening of urban landscapes' (7.2.2). Moreover, Urban Masterplans balance land use between urban expansion and the preservation of agricultural and near-natural areas (7.3.2.2).

Regional / urban level

Urban Masterplans are erected for certain city regions in Vietnam. Currently, open spaces are at risk of being disregarded in urbanisation (see 7.4.3). Strengthening the role of urban green spaces, natural and cultivated landscapes within this framework could be achieved by developing a supplemental green infrastructure plan.

The Urban Masterplan would also be the appropriate tool for incorporating and negotiating findings from urban metabolism analyses and translating these into urban planning decisions.

Further specifications at the different scales could be made based on Zoning, Detailed plans and Architectural Management Plans (7.1.4).

10.4.2 Compatibility with planning procedures and the legal framework

Technically, the state, as the representative of all Vietnamese people, owns the land and has the right to decide on planning (Masterplans etc.), land use purposes, land requisition, land prices, handover of land use rights (Law No. 45/2013/QH13, Article 1) and even crop types (Resolution 17/2011/QH13).

However, in practice, land use rights are traded between possessors like 'fictitious commodities'(Harms, 2013, p. 139). Planning processes in Vietnam have been criticised for remaining 'largely an internal government exercise, characterised by considerably unclear relationships, hierarchy, timing, and accountability among different types of plans' (World Bank, 2012, p. 13).

As a result, many peri-urban and urban farmers face uncertainties, and many are not able to continue farming or provide for the local urban population due to excessive urban development fuelled by land speculation (7.5.2). The 'tabula rasa' mentality – or *giai toa* – has often led to eliminating any components of remaining natural elements and the grown cultural landscape (7.4.3).

In recent years, there have been attempts to make the planning system more transparent and participatory. The first time that public feedback to urban development policies was considered and documented was in the course of the 2013 Land Law amendment (Hansen, 2013, p. 36). Moreover, Vietnam aims to improve access to land-related information online, particularly on land use planning, which is now required by law. Some districts also publish information on compensation and resettlement (World Bank, 2014, p. 12).

Collaborative and participatory planning and decision-making have been declared internationally as a requirement for sustainable development (SDG 16 and New Urban Agenda paragraph 13b). The National Habitat III Report acknowledged that Vietnam needs to further adapt planning institutions and procedures to achieve this requirement and to create plans which are more responsive to local conditions (7.2.1.3). Engaging in green infrastructure and PGI planning could be used as a real-life laboratory to jointly approach this objective with stakeholders involved in urban agriculture practices. PGI, as a cultivated and productive type of green infrastructure, is based on the commitment of a wide variety of actors – ranging from individuals and groups of civil society to farming professionals. Movement towards more process-oriented, more deliberate transformation processes would promote commonly defined development goals and integrate the knowledge and needs of relevant stakeholders; this would also encourage identification of particularly valuable landscape structures and a more integrative planning process.

More participatory planning processes would also lay the foundation for shared responsibility in terms of the resource-consuming maintenance of green spaces. Ultimately, many of the observed practices of urban agriculture take place in public spaces and thus contribute to the maintenance of these spaces. Observations in the context of this work have shown that citizens' sense of responsibility sometimes even goes so far as taking care of sidewalks and street trees (see 7.4.4 and Figure 32). Operationalising the share of responsibilities would require good coordination and common ideas and guidelines for design and maintenance. The Da Nang Green Growth Strategy has identified initiatives that could mobilise civil society for the creation and maintenance of urban green spaces, including the Women's Association, Youth Association, Farmers' Association, Veterans' Association and Labor Association (7.3.4).

Ultimately, integrating elements of PGI into new residential areas could partially count as the compensation required by Land Law 2013 for the appropriation of agricultural land (Law No. 45/2013/QH13, Article 87). In this way, damage to 'livelihood, socio-economic activities, and cultural traditions of the community' could be reduced. To a degree, this also applies to compensation for loss of plants and livestock (Article 90).

10.5 Summary and conclusion

This chapter determined how the green infrastructure approach can be used to further envision PGI and concretise potential development goals deriving from the urban metabolism analysis and exemplary scenario simulation in Chapter 9.

Developing a profound green infrastructure and PGI strategy for Da Nang presupposes political support at the national and local levels; the mandate of the city; and intense planning processes between planners, administration, scientists and urban residents, particularly those who actively manage, maintain and develop green infrastructure and PGI. Furthermore, this chapter illustrates which further steps could be taken to operationalise the findings from the assessment of urban agriculture and the urban metabolism analyses by drawing on the green infrastructure approach.

Green infrastructure grew from over a century of planning discourses on urbanisation in Europe and the United States but has only been consolidated in the past decade. The approach is not yet common in Vietnam but fits national and local planning goals and complements both the popularity of tending to green spaces and urban agriculture among citizens and internationally declared goals. Green infrastructure can anchor PGI in the region and can be used as an instrument to support local planning goals regarding climate change adaptation, food security, biodiversity and the supply of recreational green spaces (10.1).

Potential sites for a green infrastructure network can be compiled by considering continuous landscape areas shaped by distinct topographies, ranging from near-natural, cultural, designed and spontaneously grown vegetation and designed green spaces. Additionally, implications and opportunities caused by ongoing urban development are reflected (10.2).

Pressing issues and related planning goals in Da Nang guided the drafting of a possible city-wide vision for a green infrastructure network with PGI as a core element. For two exemplary sites, characteristic functions, spatial dimensions, and indicated atmospheres are sketched as possible spatial solutions. The integration of urban agriculture into a coherent green space system is a major opportunity to interlink and strengthen existing green space elements to contribute to local goals of improving the supply of recreational green spaces, food security, climate change adaptation and biodiversity (10.3).

Finally, further links to the existing planning framework and practices were outlined. The legal framework of Vietnam theoretically creates extended opportunities to manage land use rights and design the city in the interests of the public. If these opportunities were exhausted, parts of the existing green structures could potentially be secured and further developed as a PGI. However, planning processes would need to be more participatory as well as more considerate of existing practices and landscape peculiarities. This was also an outcome of Vietnamese reviews on the progress towards the SDGs and New Urban Agenda. Working with the existing inventory of urban agriculture practices and places could serve as a 'real-life laboratory' for adapting planning practices and organising urban green space maintenance around shared responsibility (10.4).

PART IV TRANSFER AND DISCUSSION

11 PGI MODEL APPROACH

This dissertation's understanding of PGI is not an entirely new approach – it is part of already existing, related concepts. Most of these concepts are still emerging and are at different stages of consolidation. Green infrastructure planning has mainly been consolidated in the past decade in Europe and the US. It is increasingly being translated into policies and also connects to previous traditions of strategic green space planning. Discourses on urban metabolism, urban food systems and the role of infrastructures are equally nascent in research and policy-making, but these require further development and more translation to be implemented into practice. As laid out in this work, there is a lack of recognition and operationalisation of urban agriculture practices as a type of decentralised infrastructure (see 1.2, 3.3.1 and 4.6).

In this work, open search movements and a series of parallel and recursive working steps were carried out using the case study of Da Nang to outline the PGI approach. The focus laid on assessing existing elements of urban agriculture and exploring visions for PGI's integration into urban development while considering its function in the city's urban metabolism. In the meta-reflection that follows, generalised working steps are described as a model approach for a potential transfer of the findings to other regions.

11.1 Trajectories of different regions

Population growth, which is linked to increase resource demand, and rapid urbanisation are mainly taking place in regions of Africa, Asia and South America. Rapid urbanisation opens up opportunities to explore different kinds of infrastructure setups based on more integrative planning to optimise urban metabolism processes. Developing and newly industrialising countries may be able to 'leapfrog' regarding path-dependencies in infrastructure development (see 3.4.1.2 and 3.4.1.3).

At several points in this work it was stated that PGI as a specification of green infrastructures is nested in a tradition of strategic green planning during major urbanisation processes in the US and Europe over a century ago (see, e.g., 10.1 and Box 5). However, PGI is an approach for exploring and strengthening *locally specific* practices of urban agriculture and therefore responds to local conditions. Moreover, major principles of green infrastructure coincide with the internationally declared Agenda 2030 for Sustainable Development, to which 300 countries are committed as of 2022. Therefore, PGI can be used as tool to make progress towards the SDGs, particularly in terms of improving nutrition and promoting sustainable agriculture (SDG 2) and providing access to green and public spaces (SDG 11.7; see also Box 5).

11.2 Initiating the planning process

Motivation to engage in PGI planning is linked to locally specific challenges and related goals, such as improving access to nutritious local produce, expanding the network of urban greenspaces for climate change adaptation and promoting biodiversity, and securing the well-being of urban residents. Openness to PGI depends on local cultural values and the societal conception of urban green spaces and urban agriculture.

Determining the possibilities for urban agriculture to become part of a city-wide green infrastructure system requires organisation and societal and political agreement. Ideally, an interdisciplinary or transdisciplinary working group is provided the resources to undertake a complex and participatory planning process with experts from the administration; scientists; and stakeholders from civil society with different backgrounds in, for example, landscape architecture, environmental and urban planning, agricultural science and water/wastewater and solid waste management. Based on approaches to urban food system and green infrastructure planning (see 4.4.5), initiating a stakeholder dialogue is key to a) understanding their motivation and current and potential future roles, raising motivation, and establishing working groups or other modes of operation to accompany the planning and implementation process; b) gathering the data and information needed.

Based on this setup, context-specific challenges and potentials can be identified, and objectives can be defined accordingly. For example, arid regions may focus on improving the efficiency of water cycles and may ensure that vegetation and agricultural practices are best adapted to limited water resources. Adapting to climate change and reducing heat island effects or the risks of urban flooding may be the impetus for engaging in PGI planning.

11.3 Creating a systemic understanding and coherent database

PGI planning requires gaining a systemic understanding of the city's social-ecological system by assessing qualitative information as well as consistent datasets, as concluded from studying established PGI-related approaches (4.5.3) and the case of Da Nang. A main contribution of this work is the comprehensive assessment of urban agriculture as a potential PGI.

Generally, analysis needs to comprise the different dimensions that condition existing and potential PGI and shape the urban metabolism:

- actual spaces to be assessed and used as a base and reference
- geographic conditions, e.g., topography and related soil quality, climatic conditions
- material and energy flows, e.g., produce from the region, nutrients, and water, which can be conceived as linking to the different dimensions
- actors and their roles, practices and motivation

Definition of context-specific key questions and priorities narrows the scope for assessments. Methods of qualitative analysis and the collection of coherent and spatially locatable datasets need to go hand in hand. Qualitative analyses serve to deepen overall understanding of the social-ecological system and its dynamics and thus to identify problem areas, qualities to be strengthened, and potential future developments.

PGI draws on the framework of urban food systems to assess urban agriculture's role in the city's urban metabolism (see 3.2). When it comes to spatial planning, green infrastructure provides an innovative framework for how to define search spaces regardless of ownership and origin and indicates what potential sites to look for (see 3.5.3.3).

There is a range of procedures outlining how spatial data can be collected and how collection interplays with existing land use information systems for urban development, urban planning and documentation over time (see Figure 14). Surveys serve to capture complex information with reference to points with a geodatabase, such as households representing different urban morphologies or social groups. Creating a geodatabase with the demarcation of plots and the actual representation of areas can be done via remote sensing and land cover classification, which are usually correlated with land use classification of existing land information systems.

The difficulty of properly assessing the spaces of small-scale urban agriculture can be addressed by defining, characterising and assessing typologies, as exemplified in the case of Da Nang (see 8.3). Targeted typologies should characterise occurring practices and enable their operationalisation in urban planning and urban metabolism analysis and simulation. They can be identified, allocated and quantified by an interlinked process of mappings, correlating and processing of existing geodata, and statistics.

Creating an understanding as well as a database was elaborated in greater depth in the Da Nang case study. The workflow is repeated here.

1. *Conduct a literature review and cultivate a stakeholder dialogue* to gain an understanding of a) local conceptions of green spaces and urban agriculture and b) current data inventory. Relevant sources include administrative land use information systems and existing plans and strategies. Expert interviews serve to bundle the knowledge that may be spread to different stakeholders and organisations.
2. *Gain a systemic understanding of the urban food system's current state and the role of urban agriculture* (see 8.1.2).

   Depending on context-specific questions, components analysis can be performed in different ways. For example, assessing the potential of urban agriculture's contribution to supplying the city region with nutritious but highly perishable horticulture produce allows a focus on food *production* and *consumption* patterns, which was the main focus of the Da Nang case study. To give another example, a better understanding of the relationship between specific cooperatives and consumers in the neighbourhood would require a more in-depth analysis of value chains and component *distribution/access*. Ultimately, urban food system planning intends to provide dietary choices that are adequate as well as sustainable. Thus, *production* and *consumption* are the cornerstones in the context of PGI.
3. *Establish a geodatabase from existing land information systems* as a planning base for creating a network of connected and multifunctional green infrastructure by collating all data of green baseline elements such as (semi-)natural and cultural landscapes, designed green spaces and elements of urban wilderness. In addition, grey sites have potential and include any surface in the city (e.g., rooftops, yards of any kind of building). Potential sources include administrative land information systems as well as others, such as the worldwide OpenStreetMap platform or the Urban Atlas of European Cities (see 4.5.2).

4. If practices of secondary urban agriculture are not sufficiently covered by existing land use information systems, it is necessary to find methods for their assessment.

   One method explored in this work is *conducting field trips and mappings* of urban agriculture typologies based on suitable parameters, which can include the following:

   - Size of the plots (e.g., large > 5 ha, medium 0.025 –5 ha, small > 0.025 ha),
   - Type of agriculture
     - Primary – 'regular' agriculture practiced on the areas designated for this in the land use plans, which are typically rather large-scale cultivated landscapes
     - Secondary – comprising types of agriculture on multifunctional spaces, such as residential gardens, parks, rooftop gardens, and others
   - Purpose (subsistence or sale)
   - Products (e.g., staple crops, horticulture, animal husbandry)
   - Special features (e.g., temporary or building-related cultivation, geographic emphasis or a specific cultivation system)

   Another possibility would be to initiate a collective mapping process together with those practicing urban agriculture, for example, using the volunteer-based open platform OpenStreetMap (see 4.5.2.2).

5. *Conflate existing geodata and mapped typologies to* examine to what extent mapped typologies are already part of existing datasets or to what extent they can be correlated.

   - If typologies can be identified manually by aerial picture interpretation, existing geodata can be processed accordingly. For example, some areas of a typology confirmed by mappings can be traced manually from aerial pictures to then look for the pattern in existing land use data. For example, urban agriculture may often be classified as 'unused land'. All polygons of this type of class can be selected and examined more closely by comparing aerial pictures and searching for and demarcating additional spaces of this typology (see 8.2.2).

   - Manually tracing areas from aerial pictures is time-consuming, but depending on the size and structure of the elements and the resolution of aerial images, typologies may not be identifiable via remote sensing (8.1.3.2). Depending on the mapped typology's context and nature, the possibilities for assessing certain typologies via remote sensing and supervised classification can be explored by consulting remote sensing experts. Technically, references collected in the field can be used as training samples for supervised automatic classification.

   - The assessment of small-scale typologies that cannot be identified by aerial picture interpretation remains difficult. Possible methods are based on taking samples and upscaling information to certain units. For example, household surveys can be conducted representatively and information upscaled based on demographic data. Alternatively, urban structure types can be classified via remote sensing with indices like density, the share of open spaces and Normalised Vegetation Index (see 4.5.2.3). On this basis, mappings can be carried out for the different structure types to upscale information, as tested in the case study of Da Nang (8.2.4).

6. *Correlate resulting urban agriculture spaces with statistics.* Administrative bodies responsible for agriculture may have an approach to generating statistics on agriculture (yields, output, spaces per food type) that deviates from the land use information systems of planning bodies. It is likely that statistics do not cover secondary typologies. Statistics may be specified for administrative units such as districts to help estimate the extent to which mapped typologies are part of existing statistics (see 8.2.5).

7. The assessed geodatabase of the typologies contributes to *understanding of the urban food system*. Comparing data on production and consumption of certain food types allows better assessment of actual supply rates and demand coverage from the region (see 8.4).

11.4 Understanding relatedness to the urban metabolism

As an extension of the green infrastructure discourse, PGI safeguards the metabolic interrelation of natural and urban spheres, particularly regarding the urban food system, by translating assessed typologies of urban agriculture into *simulation blocks* for integration into scenario simulation models. Thus, a typology's future developments can be imagined via scenario simulation, as shown in the case of Da Nang.

To build simulation blocks, a range of parameters have to be defined, including types of food, crops and cultivation technologies. Thus, the *amount of water and fertilisers needed* as well as *food supply rates* can be calculated (see 9.1). Aggregation of food types and crops must reflect local conditions and goals. It is advisable to distinguish between staple crops requiring rather large-scale plots such as rice or wheat and horticulture that generates highly perishable and nutrition-rich food, which can be fit into smaller plots within urban structures and can foster close relationships between producers and consumers. Crop types can vary drastically in terms of needed fertilisers and irrigation. However, crop cultivation rotates and does not need to be subject to detailed long-term planning visions. It is reasonable to aggregate crop types to an extent when considering the city scale to understand the orders of magnitude of flows. Crop types can be better differentiated at smaller scales.

The availability and application of *simulation models* for urban metabolism in urban planning seems to be a long way off (see Box 2). In Da Nang, the simulation model used was an outcome of the 'Rapid Planning' research project, with model development led by project partner IFAK based on their software dynamic simulation environment SIMBA#, which emerged from the field of wastewater and water systems (see 9.2.1). The 'Rapid Planning' simulator is in the early stages of development (see 12.3.2).

To date, urban metabolism simulation models are underdeveloped, and there is still a lack of established, user-friendly software. However, a general trend towards digitisation and computer simulation that supports planning can be observed (e.g., in climate research).[40] As an interim solution, basic calculation of flow dimensions and potential interrelationships can be explored manually with Excel sheets (e.g., food demand and supply in the region or coverage of irrigation needs through potential greywater).

Depicting the status quo of urban metabolism is based on current land use and infrastructure setup as well as modelled generation and consumption patterns to envision and simulate potential future development. 'What if' scenarios are a tool for conducting participation processes and paving the way for informed negotiation of interests and decision-making. An initial model depicting the urban metabolism can be prepared by collating data and filling in data-gaps via expert consultations and assumptions. The initial model can then serve as a foundation for discussion in workshops. The physical extent of PGI elements connected to the setup of other infrastructures can be visualised and discussed. Simulation allows for review of resulting resource use efficiency, supply rates and environmental impact, whereby the informative value of the model depends on the availability and quality of the data and sub-models. Plausibility checks are required to possibly correct input data and improve results.

PGI could be the focus of urban metabolism analysis and simulation, but it could also be an integrated part of a larger project framework with equal analysis of all infrastructure sectors.

In recursive feedback loops, different test setups can be simulated to address certain goals and optimisation parameters. Decisive aspects for PGI include the following points.

- Benchmarks for food supply rates may be assessed at different scales, such as city administration areas or continuous landscapes in the region, at the national level or in relation to distinct supply regions. In this context, modelling greenhouse emissions of 'food miles' may be beneficial to decision-making and goals for climate change mitigation.
- Defining certain area sizes for PGI can also be done in the context of the other infrastructures and calibrated so that materials like greywater or rainwater peaks are optimally utilised.
- Moreover, defining parameters for PGI as part of a larger green infrastructure network could be derived from targeted green space supply standards per person or in relation to building density, which is particularly relevant for urban expansion areas.

Overall, it is advisable to separately simulate grown urban structures with already established infrastructure systems and their possible need for optimisation and the construction of new urban expansion areas. The latter surfaces opportunities for the implementation of completely new and integrated infrastructures (9.2.2).

Scenario simulation of the urban metabolism helps to imagine processes of urban growth and to better understand the changing availability of resources; future exhaustion levels; and the dynamics between citizens' needs driving resource consumption, generation patterns and constraining factors (see 9.2.3).

The newly generated perspectives can be used to reflect previously defined normative values and goals. For example, given a fluctuating supply situation in the context of more frequent economic and social-ecological crises (e.g., weather extremes due to climate change, pandemics), an urban region could decide

[40] For example, under the BMBF Programme Urban Climate Under Change [UC]^{2,} PALM-4U software was developed, which is a meteorological model system for urban area. In a second phase, the module A – MOSAIK Model-based city planning and application for climate change is under further development to meet the needs of municipalities and other practical users to run simulations for the entire city or specific sites in high-resolution

that a certain benchmark of food should come from the region, which in turn has a setback effect on land use and thus spatial planning.

11.5 Integrated spatial planning and implementation

This work drafted an initial vision of a green infrastructure network with emphasis on PGI which could serve to initiate discussion (see Chapter 10). The considerations in the following paragraphs are based on the derived conceptual approach of PGI (see Chapter 4), the review of approaches to operationalising PGI (4.4) and the author's experience as a practicing landscape architect.

Understanding urban metabolism processes and testing potential development paths goes hand in hand with spatial urban planning. Modelling and simulation of the urban metabolism must follow contextualised parameters of spaces and processes. Deriving these spatial input parameters (e.g., land use and population density) for simulation is a task of urban planning. Simulation results can lead to decisions on new norms for spatial planning, which then need to be retranslated into draft urban layouts, as exemplified in the case of Da Nang (10). Hence, the layout and input parameters for simulation must be adjusted and scenario results reflected in recursive feedback loops.

As part of green infrastructure, PGI stands for a strategic spatial planning approach to *designing a network of multifunctional* and *connected* green spaces and creating a link to the urban food system and urban metabolism discourse (3.5.3.3). From the comprehensive assessment of existing and potential sites (11.3), a *physical layout* is sketched.

It is important to derive such plans at the scale of the entire city and ideally beyond administrative boundaries to consider continuous landscape areas. Depending on the local planning tradition with regard to green spaces, previously developed city-wide green space visions can be used and, where necessary, updated to reflect the principles of PGI. A supplementary but individual green infrastructure plan reasons through future developments of the socio-ecological urban system based on the logic of nature and landscapes, avoiding the risk that open spaces are disregarded as remnants of expanding urbanisation (10.4).

Since citizens and professional farmers are the main actors in PGI, their role needs to be acknowledged appropriately. In line with the key green infrastructure principle of social inclusion, planning needs to be carried out in a collaborative and participatory process (11.2). The beneficial momentum of PGI as a decentralised infrastructure lies in its adaptability to changing conditions and its appearance as a tangible space. PGI allows citizens to experience and co-create processes of the urban metabolism which reinforce a sense of agency.

PGI addresses synergies between resource-consuming maintenance of public spaces and citizens' commitment to sharing responsibility, as observed in Da Nang (7.4.4). The process requires good coordination and shared development of guidelines for the design and maintenance of PGI.

Overall, the reciprocal steps of urban metabolism analysis, scenario simulation, and integrated spatial planning need to be elaborated by the interdisciplinary, transdisciplinary working group to lead to a better informed negotiation of interests and a redefining of values and goals.

Based on the results, the working group may develop recommendations for adapting existing plans and legal regulations on land use or even outlining an original planning framework. For example, certain specifications for green areas could be set in the respective urban development regulations, and investors could be obliged to implement them. Moreover, regulations may need to be adapted to secure land use rights for urban farmers and encourage ongoing movements of urban agriculture.

Planning decisions impose a direct setback on the ever-developing urban system. They induce changes in the urban layout, policies, the actor's responsibilities and practices, and resource management and flows of the urban metabolism. These changes need to be monitored and factored into further planning processes. In sum, all of the described steps require regular updating of the database and hence simulation and planning.

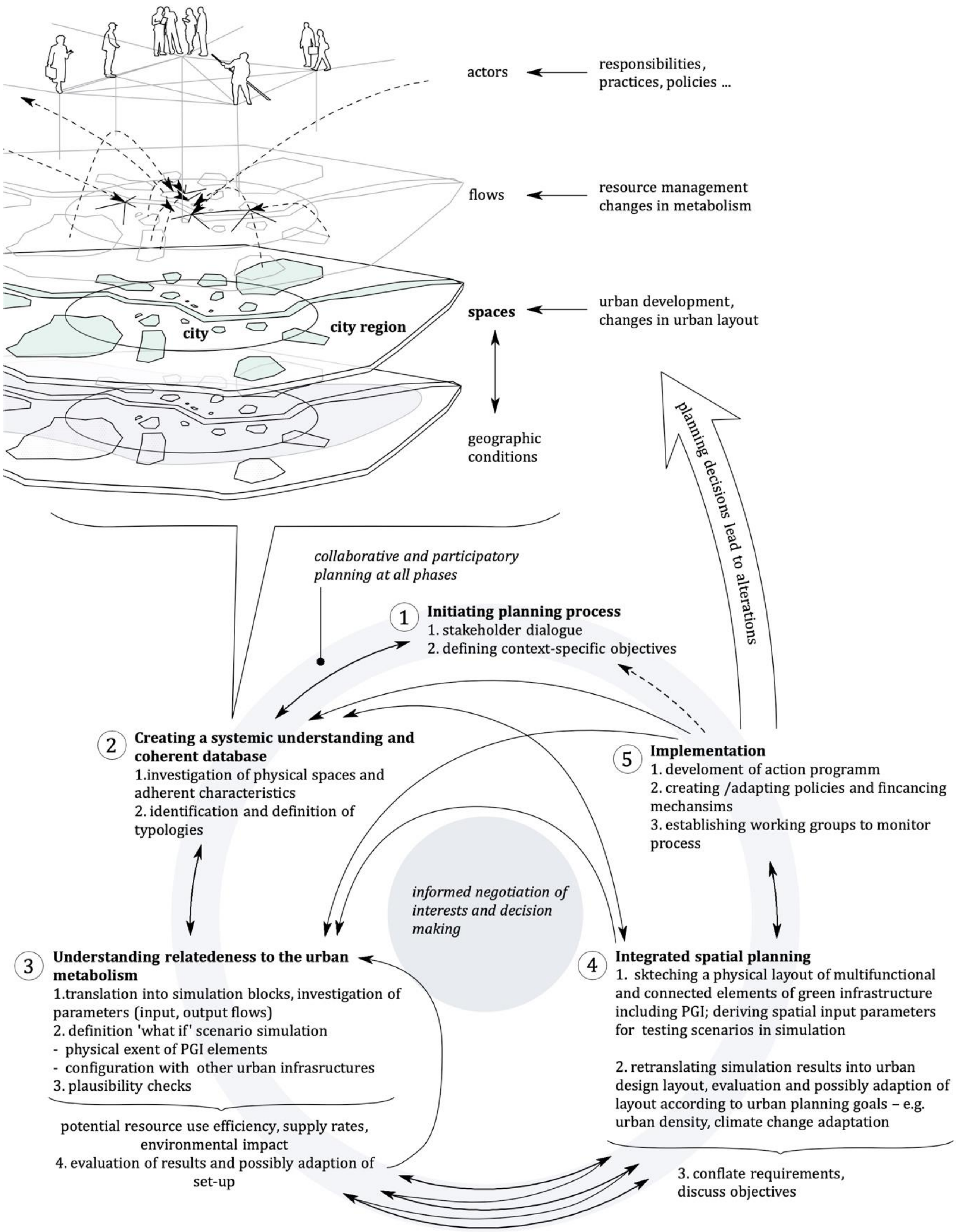

Figure 65 PGI Compendium and overview of possible working steps

12 DISCUSSION OF THE RESULTS

In this chapter, the key findings of PGI as a conceptual approach are discussed in relation to the research objectives formulated in Chapter 1. The potential contribution of PGI in terms of tackling global challenges is considered (12.1). The methods for laying the foundation for PGI planning in terms of assessing urban agriculture and its role in the urban metabolism are critically discussed, and research constraints are described (12.2). Finally, an outlook for further research and practice is proposed (12.3).

12.1 Global problems and PGI's potential for optimising the urban metabolism

After humanity seemingly evaded the natural regulations of the (urban) ecosystem's 'carrying capacity' by expanding and distorting the city's urban metabolism into a 'global hinterland' through technological progress (Langhorst, 2016; Prytula, 2011), the interdependency of urban and natural systems has become evident in light of the exhaustion of regenerative capacities on the global scale (Giseke, 2018). Human-induced planetary alterations and their negative consequences on the biosphere are difficult to grasp both spatially and temporally. There is no single solution for dealing with these problems. Rather, systemic interrelationships need to be better understood, particularly regarding the role of resource utilisation and land use practices. This work focusses on optimisations of land use and urban planning through PGI.

> The city is, therefore, clearly seen as a stage on which societal futures will play out. Urban areas are also a stage open to design and intervention: shaping cities for a desired (and often as-yet immaterial) future. *(Caprotti, 2018, p. 2)*

The Anthropocene debate reinforced the perception that cities represent crucial fields of action, as established in the 2030 Agenda for Sustainable Development (Goal 11). Likewise, the New Urban Agenda states, 'cities can be a source of solutions rather than the cause of the challenges that our world is facing today' (United Nations, 2017, p. iv).

Major leverage lies in shaping the properties and capacities of the built structures and especially *infrastructures*, or the 'nerve networks of the superorganism humanity' (Radermacher, 2005, p. 104), which form 'a series of interconnecting life support systems' (Gandy, 2005, p. 28). The way large-scale infrastructures are built appears to obstruct renewal processes, and current discourse leans towards exploring more decentralised structures (Kropp, 2018) (3.4).

In many urbanising regions, the loss of agricultural areas has decoupled local relations between food production and consumption and can hinder the availability of food, especially fresh produce. The loss of green spaces and the increase of sealed soil foster vulnerability towards local aspects of climate change (2.2).

The main idea of PGI is to give more weight and more physical space to multifunctional, connected green space systems and to acknowledge their role as a *'soft', 'living'* infrastructure (Bélanger, 2017; Perrotti, 2015) because green spaces and particularly urban agriculture tend to be marginalised in urban planning (4.6).

PGI combines the agenda of green infrastructure and food system planning to contribute to urban residents' well-being and *optimise the urban metabolism*. Accordingly, cities as urban ecosystems need to better integrate natural ecosystems to close resource loops (Zhang, 2013, p. 463). PGI can facilitate the use of urban resources emanating from urban wastewater and organic solid waste to render nutrient and water flows more sustainable along with other supply and disposal infrastructures (e.g., water, wastewater, solid waste, energy; (Skar et al., 2020). In terms of increasing sharing of regional produce, PGI can contribute to increased food security, expand the choices for healthy and sustainable diets and expand choices to actively participate in growing food and more sustainable resource use modes (Cabannes and Marocchino, 2018).

12.2 Critical reflection of the tested approach and results

After the conceptual approach of PGI was derived, the case study Da Nang was used to test methodologies and answer the three research questions (RQ). The following sub-sections reflect on the extent to which the research questions were answered.

12.2.1 RQ1) Creating a spatial planning base: How can urban agriculture be better characterised and assessed in its spatial dimension?

This research is driven by the insight that practices of urban agriculture are often overlooked in planning processes because of their dispersed and informal character and due to the fact that related aspects are likely dealt with by different authorities (see 1.2).

This work identified one possible approach to tackling urban agriculture assessment. Da Nang represented a suitable case due to the high prevalence of urban agriculture and the fact that it is not covered by existing plans and statistics and thus is not subject to the urban planning processes. In this work, the author developed assessment procedures as an external researcher. If this task were carried out by local stakeholders, the process would have likely been different. In the research framework, an interlinked process of mappings and geodata processing was completed to identify characteristic typologies and their spatial assessment.

The advantages and disadvantages of the assessment procedures were detailed in Section 8.5. Working with typologies to grasp recurring structures of urban agriculture is a common practice (3.3.4) proven to be useful in facilitating the assessment process and paving the way for further planning processes. In short, typologies identified via aerial imagery interpretation can be assessed in great detail. The expense of identifying the elements depends on their structure and size as well as the quality of existing land use geodata. For example, elements of urban agriculture may already be allocated to certain classes such as 'unused land', which facilitates the demarcation process.

As an external researcher in Vietnam, one constraint was accessing geospatial data from the official land use information system. This was solved by networking within the 'Rapid Planning' project; this solution might have been different with an official 'mandate' for PGI planning from the city.

Overall, tracing from aerial imagery based on real-life impressions proved suitable for capturing the social practices of urban agriculture interwoven into the urban structure. The technique is also practiced and encouraged by OpenStreetMap. As an alternative, the mapping and tracing process could also be carried out by citizens with the tools of the OpenStreetMap platform given strong coordination of classifications and demarcation of elements. A disadvantage is that the manual process is time-consuming. To further progress the approach, potential support through supervised automatic classification can be investigated (see 12.3.1).

It has remained challenging to identify small-scale urban agriculture of less than 0.025 ha. The tested approach to draw on automatically classified urban structure types and the NDVI and conducting sample mappings had limitations since it was difficult to properly assess the single sample plots and upscale the data (see 8.2.4.3). Through an additional correlation process with the 'residential' land use class, it was possible to make a conservative estimate of the generalised share of productive small-scale elements within residential areas.

Overall, characterisation and spatial assessment of the typologies made them tangible for further analyses and planning processes. This was demonstrated by further urban metabolism analyses (Chapter 9) and envisioning a PGI as part of a green infrastructure framework (Chapter 10).

12.2.2 RQ2) Understanding urban agriculture's role in the city's urban metabolism: How much food is produced now, and how much food could be produced if urban agriculture were integrated into rapid urban development as a PGI and part of a green infrastructure system? What are fruitful links with other urban infrastructures to optimise the city's urban metabolism?

This work strove to gain an understanding of how much local urban agriculture contributes to the local food supply. To date, only primary agriculture is covered by statistics, and the food group of vegetables is largely left out. The city-wide assessment of intra-urban vegetable production sites in this work made it possible to reveal urban agriculture's contribution, which – depending on which database is consulted regarding consumption rates – covers about 5%–10% of demand. In this work, little could be found about vegetable production within primary agriculture (see 8.4). The stated amount of 121 ha of urban agriculture sites dedicated to vegetable production is probably far too low, particularly because farmers intend to shift to high-value crops including vegetables (see Table 11).

Participating in the 'Rapid Planning' project and jointly developing a simulator of the city's supply and disposal infrastructure made it possible to integrate urban agriculture into the simulator, further elicit its systemic links to other infrastructure and ultimately explore potential future developments in which urban agriculture is an integral structure of the urban extension areas (9.3). In the framework of the project, it was possible to develop one alternative scenario for 2030 with assumptions for each urban agriculture typology. In this setup, supply rates of vegetables within the city region could be increased from 7% to 13% despite a doubling of the population and demand. In comparison to official plans for urban development, fruit supply rates would not drop from 15% to 3% but could be stabilised at 7% (9.2.3.1). Thus, relationships could be fostered between local producers and consumers, and the growing demand for 'safe vegetables' could be met to a larger extent.

As year-round production is possible due to climatic conditions, consumption of produce from the region likely reduces energy consumption for transportation and cooling. It can be assumed that due to shorter distances and quick supply, food losses due to spoilage are reduced. These aspects need further elaboration and were not covered sufficiently in the study (9.3).

By means of an advanced wastewater system setup in urban extension areas, water demand for irrigation could be covered by greywater to 100% during the winter season and to approximately 40% during the dry season, with irrigation often needed to compensate for a prolonged absence of rain. If the occurring organic waste were utilised to generate fertilisers, the supply would far exceed the demand for agricultural areas within the city region and could be cycled back into other cultivation areas in the region (9.2.3.2).

Formulating this setup was challenging, due to the complexity of urban metabolism and the interplay of different disciplines. The investigations would be improved by exemplifying the ideas at smaller scales to solidify linkages and potential design solutions. While drawing from many different fields, the work would further benefit from other experts' contributions. Assumptions on the metabolic processes of urban agriculture and cultivation techniques could be reviewed and verified by agronomists. Environmental impact assessments of PGI's influence on regional eutrophication potential and CO2 emissions require further research (see 9.3 and 12.3).

12.2.3 RQ3) Envisioning PGI: How could these types of spaces look, and how could their potential contribution to local development goals be highlighted? What planning steps are necessary to further elicit this kind of PGI vision?

The analyses of urban agriculture should not serve an end in themselves but are meant to become part of the planning processes and design of the city.

In this work, PGI is understood as reaping the potential of hitherto informal single elements of urban agriculture by subjecting them to an active and holistic planning process as part of the city-wide green infrastructure. An initial draft characterising Da Nang's green space was sketched, and model-like assumptions from the scenario simulation were translated into design solutions and exemplified at two sites. These drafts represent an initial vision of how PGI could look by strengthening existing valuable elements of urban agriculture (e.g., along riversides) and creating new development sites inspired by socially established practices of urban agriculture.

The case study highlighted PGI's potential contributions regarding alleviating a multitude of challenges connected to rapid urbanisation in Da Nang, including a significant lack of green space, high vulnerability to the effects of climate change in terms of urban flooding, rapid turnover of prime agricultural land, and associated socio-economic changes with farmers losing their land and occupation. Vietnam is estimated to lose 10% of its cropland due to urbanisation between 2000 and 2030, which amounts to 15.9%

production loss as near-urban cropland is more productive (1.41 times more productive than the regional average; (Bren d'Amour et al., 2016). Strategies are needed to compensate for this loss if Vietnam strives to continue on its path toward national food security (7.2.4).

At the same time, Da Nang is characterised by a rich culture of urban agriculture. Citizens, many of whom may be former farmers, engage in greening the city and growing food in any spot imaginable.

PGI represents the missing link to operationalise these structures as crucial (green) infrastructure. Based on the previously assessed typologies, a vision for a green infrastructure network with PGI as an integral element was drafted. The multiple potential functions of the network's elements for contributing to overarching planning goals were highlighted. While PGI's contribution to the food supply was detailed, how it contributes to climate change adaptation, promoting biodiversity and improving the supply of recreational green need further research.

A challenge was the hypothetical planning level for these drafts since an actual planning process would be predicated on far-reaching political and societal support and participation and inter/transdisciplinary planning and building. For example, the design proposal for the 'agricultural urban neighbourhood' is closely guided by existing layout standards. Creating suitable and sustainable urban design would require launching an interdisciplinary design process with architects and urban planners.

12.3 Outlook for further research and practice

In this thesis, PGI was defined drawing from emerging approaches, mainly urban metabolism, the urban food system and green infrastructure – all of which require further research and translation into planning. In this context, PGI addresses the gap of assessing and operationalising structures and practices of urban agriculture for urban planning processes. Focus areas of future research further underpin the PGI approach.

12.3.1 Further refinement in assessment procedures

As laid out in the meta-reflection on the working step 'creating a systemic understanding and coherent database' (11.3), this work explored new procedures for assessing the physical extent of urban agriculture as a potential PGI in the form of tangible typologies (8.3).

In remote sensing, the software can be trained for automatic land cover/land use classification by interpreting different parameters, including the texture of pixels (see 4.5.2). In the 'Rapid Planning' project with remote sensing experts in the consortium, it was impossible to fully assess the spaces and grasp their characteristics through remote sensing and automatic classification, which is why field trips and manual data processing were carried out (see 8.1.3.2). Apparently, visual interpretation of the combined information of real-life impressions in the field paired with aerial images cannot easily be replaced by artificial intelligence.

However, the process of manual tracing has the disadvantage of being time-consuming. Due to quick changes in the urban morphology during urbanisation, it is desirable to be able to update information easily. Field explorations are crucial to understanding the sites and their characteristics, but it could be explored how training samples from field references of sites can be used to improve the accuracy of automatic supervised classification. An automated preselection of eligible green spaces in the city could facilitate the assessment.

12.3.2 Further urban metabolism research and refinement in software development

Urban metabolism research increasingly examines energy and material flows at different scales but is most often focused on sectoral questions such as wastewater infrastructure planning or the Life Cycle Assessment of single products or services (Prytula, 2019) (see Box 2).

The rather slow pace of practical implementation of urban metabolism study findings at the municipal level is linked to a lack of tools to conveniently assess and manage urban metabolism's complexity and data streams. As elaborated regarding the working step 'understanding the relatedness to the urban metabolism' (11.4), ready-to-use simulation models for urban metabolism analysis and planning connected to the city's physical geodatabase are currently not available.

The 'Rapid Planning' project aimed to develop a comprehensive methodology and simulation model to depict the city's metabolism in terms of its supply and disposal infrastructure. This work contributed to integrating urban agriculture as part of the urban food system into the model, which required intensive preparatory work and conceptualisation (see 9.1). Data on the extent of PGI typologies was integrated into the model as numerical values. An interface to integrate shapefiles into the 'Rapid Planning simulator' was developed only towards the end of the project. The interface between the urban metabolism model and the geographic information system is crucial for interlinking the processes of a) assessing and targeted influencing of metabolic flows and b) urban spatial planning. Further research and software development on this aspect is required.

12.3.3 Exploring how the PGI approach could be established in planning practices

It would be insightful to further research how the PGI approach and an urban metabolism model could be established in planning practices and how planning could benefit from the PGI approach, thus validating the PGI model approach drafted in Chapter 11. This would require extended research of the case of a city region as a broad, collaborative project and 'urban laboratory'. The Da Nang urban metabolism model has so far only been developed and discussed by a small circle of scientists, administrators and a few representatives of civil society.

For such a model to optimally generate reliable planning statements, a larger discourse in the city and constant further development would be required. Ideally, the urban metabolism model would be established as an opensource application that could be collaboratively developed in a transdisciplinary approach by a wide range of actors from the fields of administration, planning and science as well as civil society. For informed planning processes, a crucial layer within this model would be the sufficient inventory of existing urban agriculture and green spaces, as outlined within the PGI approach.

Establishing the process of using an urban metabolism model to run different urban planning scenarios would require further development of a common understanding of how the results should be interpreted and evaluated. On a practical level, how the work processes of urban and landscape design and the generation of model statements can be intertwined in fruitful feedback loops needs further exploration. Furthermore, it should be clarified at which planning stage it makes sense to run scenario simulations and which parameters should be defined (e.g., required irrigation per unit area of a certain type of urban agriculture) and which planning goals exist and should be considered (e.g., proportion of green space per capita).

If the urban metabolism model was established as an opensource tool, it could be used in urban design competition proceedings, and competition entries could be enriched with information on the proportions of PGI and potential food production. Additionally, the average rainwater and greywater occurring at a development site could be determined at an early stage in the planning process, and corresponding units of PGI utilising these water resources could be designed accordingly.

GLOSSARY

Anthropocene: because the human impact has intensified significantly since the onset of industrialization and has emerged as the most influential factor on Earth, inscribing itself in its geological depths, the term Anthropocene is proposed for the current geological epoch (see Box 1)

Biosphere: the total sum of all ecosystems that form regenerative, adaptive, self-organising systems on which the technosphere is dependant (3.1.2.1)

Green Infrastructure: is a strategic planning approach to develop networks of green (and blue) spaces that are designed and managed to enhance their ecosystem functioning, thus contributing to the well-being of humans and nonhumans. It forms a continuum from 'green' to conventional 'grey' infrastructures (see Box 5)

Ecosystems: communities of living organisms and their non-living environment that inseparably interrelate and interact (3.1.2.1)

Hinterland: stands for the *'many regions needed (1) to supply all the goods used in a particular region and (2) also to dispose of and dissipate the off-products (e.g., wastewater, off-gas, solid wastes) of the region'* (Baccini and Brunner, 2012, p. 36)

Material Flow Analyses (MFA): refers to analysing flows and stocks of a good in a defined system and is used to examine metabolic processes in the context of human activities. It is a base for all methods assessing and evaluating an urban metabolism (Baccini and Brunner, 2012, p. 78 and p. 105)

Urban agriculture comprises all agricultural practices in the intra- and peri-urban area and can be conceived as the main physical infrastructure of the urban food system (see 3.3)

Urban food system: framework to assess different modes of urban food provisioning – consisting of the systemic components production, processing, distribution/access, consumption as well as disposal respectively valorisation of food wastes (see Box 4)

Urban metabolism: framework for modelling a cities energy and material flows. It can be used to analyse how urban areas function with regard to resource use and the underlying infrastructures, and the relationship between human activities and the (natural) environment (see Box 2)

Urban systems: are understood as nodes with a high density of human population, goods, and information that are globally interconnected according to the Netzstadt concept (Oswald et al., 2003)

Primary urban agriculture: as a counterpart to secondary urban agriculture, primary refers to conventional practices of agriculture at designated areas. In comparison to secondary practices, primary agriculture tends to be larger in scale, tendentially located at the peri-urban area scale (Giseke et al., 2015b, p. 32) (see also 8.2.1)

Productive green infrastructure (PGI): elements of urban agriculture assessed and operationalized as part of a strategically planned green infrastructure network (see 4.1).

Secondary urban agriculture: as a counterpart to primary urban agriculture, secondary refers to agricultural activities taking place at areas not officially designated for agriculture and is thus tendentially more integrated into the urban structure and smaller in scale (Giseke et al., 2015b, p. 32) (see also 8.2.1)

Simulation model: in this thesis refers to the 'Rapid Planning simulator' developed in the course of the 'Rapid Planning' depicting the urban metabolism of the case city focussing on the nexus between the systems of food, water, energy, waste, and wastewater (see 9.2.1)

Sustainability: outlines the idea of urban and natural systems co-existing permanently based on balanced exchange processes. Existential human needs on a global level are satisfied without endangering the physiological conditions of life on Earth (see Box 3)

Technosphere: refers to urban systems and their supply and disposal structures dependent on the biosphere (3.1.2.2).

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