Doctoral School in Environmental Engineering

Analyzing ecosystem services and green urban infrastructures to support urban planning

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Once you find your shoulders dropping
And your speech gets slow and hazy
You better change your way of being
Before you found your brain got lazy
You can build a better future when you join the winning team
If you desire a bright tomorrow, you must build a brighter dream
Dare to let your dreams reach beyond you
Know that history holds more than it seems
We are here alive today because our ancestors dared to dream
From Africa they lay in the bilge of slave ships
And stood half naked on auction blocks
From eastern-Europe they crowded in vessels overloaded with immigrants
And were mis-named on Ellis island
From South America and Mexico, from Asia, they labored in sweat shops
From all over the world, they came to America
Many shivering in rags, and still they dared to dream
Let us dream for today and for tomorrow
Let us dare to dream

[Maya Angelou]

Aknowledgements

No thing would never have happened just by myself. In this nomad journey that the PhD has been to me, I went through places and people. For me it is just an honor (and a pleasure!) to go back to each pearl of the necklace, say thanks and smile.

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Contents

List of Figures

List of Tables

Summary

Cities represent at the same time a kaleidoscopic diversity -in terms of situations, challenges, morphology, people- and an ensemble of same tendency: growing. In the majority of cases, such growth determines on one hand a growth of the demand for resources and on the other hand more and more limited resources at disposal to satisfy such demand, due general trend and need to substitute green areas with built-up areas.

However, if goal of any plan and policy is human wellbeing, the availability of green areas in city and, more general, of ecosystems is crucial. Hence, the constituents of human wellbeing can be summarized into four basic types of capital that are necessary to support a real, well-being–producing economy: built capital, human capital, social capital, and natural capital (Costanza, 2008a). How shall we preserve, manage or increase such capital to assure and increase wellbeing in cities are questions that decision-makers face every day.

Ecosystems contribute to human wellbeing though the provisioning of goods and services, also known as ecosystem services (ES). These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005). However not all ecosystems provide ES to the same extent and depending on physical characteristics of the ecosystems or their location within the city, ES flow differently. The consideration of ecosystems and ES in the planning practice can play an important role in coping with urban challenges, aside to their potential to ameliorate quality of life.

Urban planning represents one of the tools administrations have to influence the distribution of ecosystems and ES in a city, and to determine the benefits they provide and, more specifically, to re-determine the number, the location and type of beneficiaries reached (Kremer et al, 2013). Inclusion of the ES concept in the planning practice can lead to strategic the creation or restoration of Green Urban Infrastructures (GUI) in a city to maximize the provisioning of a specific ES. GUI can be described as hybrid infrastructures of green spaces and built systems, such as urban forests and wetlands, parks, green roofs and walls, that together can contribute to increase city resilience and human benefits through the provision of ES (Naumann et al., 2010; Pauleit et al., 2011; European Environment Agency, 2012). Additionally, Ecosystem-based measures can be specifically designed to support cities to adapt to climate change and this approach take the name of Ecosystem-based Adaptation (EbA).

Despite the awareness of environmental, social and economic advantaged coming from the application of the ES concept in the planning practice (through the application of

Ecosystem-based measures such as the creation and restoration of GUI or more specifically through the application of the EbA to increase urban resilience to climate change), there is limited evidence about the application in the planning practice. Insufficient understanding of ecosystems and ES functioning by planners and the lack of tools and methods for ES assessments at the urban scale may hamper the inclusion of Ecosystem-based measures and put further from reality the design of sustainable and equitable cities.

Goal of this work of this work is to contribute to mainstream ES knowledge into practice. Towards the achievement of this goal, it is crucial to understand the extent to which the ES concept is currently included in urban planning, and to identify the type of information that can most effectively support decision-makers and planners in adopting ES knowledge, and specifically Ecosystem-based measures in their “everyday” urban planning. The work is organized in four specific objectives.

First objective of this research is to provide an overview of the current state of the art related to inclusion of Ecosystem-based measures in urban planning and discuss, and use it identify and discuss the main shortcoming and propose possible solutions.

ES recent scientific literature has shown a growing interest to assess climate adaptation plans at the urban level, but little information is available on the combination of these two issues, i.e., the actual inclusion of Ecosystem-based Adaptation (EbA) measures in climate adaptation plans at the urban level. First objective of the thesis is to address this gap by developing a framework for analyzing the inclusion of EbA in urban level climate planning, hence, apply the framework to a sample of climate adaptation plans in Europe.

Second objective of the research is to develop an approach to estimate the cooling capacity provided by Green Urban Infrastructures to support urban planning.

To provide a contribution in response to the need of ES assessment to support urban planning, overtly designed for ES assessments at the urban scale, we focus on one specific ES (cooling) and build a methodology for assessing the cooling capacity of different ecosystems in cities. The aim here is to propose an approach for estimating and mapping the cooling capacity provided by GUI to generate useful information to support planners and decision-makers in the design and enhancement of GUI.

Third objective of this work is to test the application of ES assessments in two case studies.

Because of the pivotal role of practice in this work, the third objective deals with testing the applicability of ES assessments and the ES concept in general to exiting urban planning challenges. Two case-study applications considered, each addressing a specific policy and planning question. In the first case study (Trento, Italy) we tested again our cooling capacity assessment methodology and additionally mapped the flow of ES with the intention to apply the results to the identification of priority brownfield for intervention, based on the best cooling capacity expected. In the second case study (Addis Abeba, Ethiopia) we applied a multiple ES assessment and we also considered the demand for ES with the intention to apply the results to identify priority neighborhood for environmental actions

Fourth and last objective of the thesis is to develop guidance to support equitable distribution of ES in cities.

If wellbeing in cities depends also on natural capital, it is crucial to pursue equitable distribution of resources (and more specifically of ES) among citizens in a city. In the practice, equitable distribution is assessed through general urban standards (e.g. availability of green per capita) or by applying ES assessments designed for purposes different from the pursue of equitable distribution of resources. Thus, we developed a methodology to assess equitable distribution of ES within a city. The adoption of ES assessments can provide a powerful tool to the assessment and pursue of equitable distribution of ES. Equitable distribution of the natural capital, and more specifically of ecosystems and the ES they provide, represents one of the pillars of an equitable distributed wellbeing (Costanza, 2008b; UNHabitat, 2016). ES assessments can provide a support to the analysis of ES distribution to pursue equity, by identify location of ES supply, verifying access to such ES and mapping the demand to identify possible mismatches within the city.

This work is result of the joint contribution from the ES theory and applications of findings to case studies, with interest both in the applicability of methods by users, and in the type of contributions that such applications can provide to planners. The ES concept more than a goal itself represent a tool to understand the underlying links between ecosystems, benefits provided and human wellbeing. Such understanding, if effectively used and mainstreamed in the planning practice, can be one of the keys for more livable and equitable cities.

Chapter 1

Scope and outline of the thesis

1.1 Introduction and objectives

Adapting to climate change, assuring presence of water and food and fuel, mitigating run-offs, managing liquid and solid waste, providing recreation and sense of identity, supporting the economic growth and general availability of goods that underpins it, while pursuing quality of life for all citizens. From a management point of view, cities represent an ensemble of problems to solve and needs to satisfy, in order to provide and maintain the wellbeing of their inhabitants. In particular, in terms of resource management, the growth and development of urban environments is accompanied by a demographic growth, which triggers an increase in the demand for resources, and a physical growth of the built up that affects the potential supply of resources, from both quantity and quality sides. The situation is equal to a touchpaper burning from both sides.

Costanza (2008a) summarizes the constituents of human wellbeing into four basic types of capital that are necessary to support a real, well-being–producing economy: built capital, human capital, social capital, and natural capital. Despite some disheartening trends, there is a general awareness about the fact that no human life can occur without the contribution of the natural capital. For example, in the urban planning debate the sphere of natural capital is gaining more and more relevance (UN Habitat, 2016). However, the environmental challenges faced by cities around the world are more complex now than at any other time in history (UNU, 2003). Additionally, nature-related issues, like coins, present two faces. On one hand, there is the need for conservation, need to preserve the existing natural capital from disasters and human-activity impacts. Thus, an optimal use of current understanding of ecosystems and their link with human-wellbeing represent a key to avoid environmental traps that would compromise quality of life in cities and instead would offer a variety of benefits that underpin human wellbeing (Chapin et al.). On the other hand, natural capital, which includes the ecosystems and all the services they provide, represents a promising source that only need to be unlocked, bridled and managed to provide cities the goods and services they need to improve quality of life.

Ecosystem Service (ES) are all the goods and services provided by ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005). An ecosystem is a community of living organisms and nonliving components of their environment (e.g. like air, water and mineral soil), interacting as a system (Chapin et al., 2002). Ecosystems however are not only environmental and health “issues”: they also represent important economic value. The presence or absence of functional ecosystems and their ES have impact on the strength of the economy and on the wellbeing of people (e.g. air purification, noise reduction, urban cooling and absorbing storm/flood water runoff) (Bolund & Hunhammar, 1999) . For instance, the air purification performed by ecosystems in Barcelona represents economic values of over EUR 1 million of avoided costs for the city (Gomez-Baggethun and Barton, 2013). In Chicago, the cooling value of each tree corresponds to USD 15 of avoided air conditioning costs and hospitalization expenditures due to heat-related diseases (Gomez-Baggethun and Barton, 2013). Even higher costs and values are related to flood mitigation. Hence, the presence of functional urban ecosystems represents significant economic and health benefits, while their absence implies costs.

Even though all ecosystems provide ES, different ecosystems provide different ES, according to their biophysical functioning that is determined by their physical characteristics, such as the size, the soil cover or the presence of tree (Bolund and Hunhammar, 1999; Bowler et al., 2010; De Groot et al, 2010). Additionally, ecosystems in a city are heterogeneously distributed and consequently their ES provisioning also is heterogeneously distributed among potential beneficiaries (Ernston, 2013).

Urban planning represents one of the tools administrations have to influence the distribution of ecosystems and ES in a city, and to determine the benefits they provide and, more specifically, to re-determine the number, the location and type of beneficiaries reached (Kremer et al, 2013). Thus, through the management and spatial distribution of spaces, people and resources, urban planning can create (or compromise) the links between ES that underpin human wellbeing and potential beneficiaries, alternatively defined as supply and demand for ES. Ecosystem-based measures use biodiversity and ES to help people and cities to enhance quality of life in their environments. Ecosystem-based measures include management, conservation and restoration of ecosystems that deliver ES (Munang et al., 2013a) and design and improvement of green and blue infrastructures (e.g., urban parks, green roofs and facades, street trees, rivers, and ponds). Among the most common ecosystem-based measures in cities are the creation and enhancement of Green Urban Infrastructures (GUI) (Munroe et al., 2012; Geneletti and Zardo, 2016). GUI can be described as hybrid infrastructures of green spaces and built systems, such as urban forests and wetlands, parks, green roofs and walls, that together can contribute to increase city resilience and human benefits through the provision of ES (Naumann et al., 2010; Pauleit et al., 2011; European Environment Agency, 2012).

The consideration of ecosystems and ES in the planning practice can play an important role in coping with urban challenges, aside to their potential to ameliorate quality of life. In 1999, Bolund and Hunhammar identified seven specific urban ecosystems and assessed their contribution in terms of provision of ES, and concluded that, in cities, ES have a substantial impact on the quality-of-life of the inhabitants and that they should be duly addressed in urban planning. After this seminal article, the relevance of ES consideration for urban planning gained more and more attention in the ES literature and in the general awareness (Gomez-Baggethun and Barton, 2013). In particular, Demuzere et al., (2014) presented a comprehensive analysis of the available empirical evidence about the contribution of ecosystems and the ES they provide in urban areas. Ecosystem-based measures have been increasingly promoted in the literature, as well as in policies and practices, for their environmental and socio-economic co-benefits. As an example, the European Union recent climate adaptation strategy (EC, 2013) explicitly encourages the adoption of ecosystem-based measures for climate change adaptation. The grey literature includes several collections of experiences, but they focus either on urban context in general, with little emphasis on ecosystem-based measures (EEA, 2012), or specifically on Ecosystem based Adaptation (EbA) with little emphasis on urban areas (Doswald and Osti, 2011; Naumann et al., 2011; Andrade Pérez et al., 2010). There is still limited evidence about application of EbA and general inclusion of the ES concept in the practice.

The ultimate goal of this work is to contribute to mainstream ES knowledge into practice. Towards the achievement of this goal, it is crucial to understand the extent to which the ES concept is currently included in urban planning, and to identify the type of information that can most effectively support decision-makers and planners in adopting ES knowledge, and specifically Ecosystem-based measures in their “everyday” urban planning. To start with, existing approaches unfortunately lack quantitative estimates of the potential of Ecosystem-based measures (Jones et al., 2012). In fact, methods are needed to understand and quantify how ecosystems provide ES, by spatially defining the cascade relationship between their structure, functions, ES and the related benefits (Braat and De Groot, 2012) at scale that is adequate for urban planning. Yet, many of these links remain largely unknown and this knowledge is in high demand (Larondelle and Haase 2013). To achieve its ultimate goal, this work is driven by four research objectives, and related questions, illustrated.

Objective 1: provide an overview of the current state of the art related to inclusion of Ecosystem-based measures in urban planning and discuss, and use it identify and discuss the main shortcoming and propose possible solutions.

ES recent scientific literature has shown a growing interest to assess climate adaptation plans at the urban level, in recognition of the important role played by urban areas in addressing climate change challenges. However, little information is available on the combination of these two issues, i.e., the actual inclusion of Ecosystem-based Adaptation (EbA) measures in climate adaptation plans at the urban level. First objective of the thesis is to address this gap by developing a framework for analyzing the inclusion of EbA in urban level climate planning, hence, apply the framework to a sample of climate adaptation plans in Europe.

Research questions
- What are the most common EbA considered for climate change adaptation in cities to respond to the variety of climate change hazards?
- To which extent are EbA considered and described in climate adaptation plans?
-In what parts of the planning documents are EbA measures present? Are they consistently included from the baseline information up to the end or are there weaknesses that may hamper their application?

Objective 2: develop an approach to estimate the cooling capacity provided by Green Urban Infrastructures to support urban planning.
To address the scares application of EbA in urban planning, by way of example, we focus on one specific ES (cooling) and build a methodology for assessing the cooling capacity of different ecosystems in cities. The aim here is to propose an approach for estimating and mapping the cooling capacity provided by GUI to generate useful information to support planners and decision-makers in the design and enhancement of GUI.

Research questions
- Which physical characteristics of a Green urban infrastructure determine its cooling capacity?
- Which is the combination of physical characteristic that maximize the provisioning of cooling?
- Given specific physical characteristics, what decrease of air temperature does a GUI provide (in °C)?

Objective 3: Testing the application of ES assessments in two case studies.

ES research is a mission-oriented discipline, and as such it should be user-inspired and user-useful (Cowling et al., 2013). Therefore, because of the pivotal role of practice in this work, the third objective deals with testing the applicability of ES assessments and the ES concept in general to exiting urban planning challenges. Two case-study applications considered, each addressing a specific policy and planning question. In the first case study (Trento, Italy) we tested again our cooling capacity assessment methodology and additionally mapped the flow of ES with the intention to apply the results to the identification of priority brownfield for intervention, based on the best cooling capacity expected. In the second case study (Addis Abeba, Ethiopia) we applied a multiple ES assessment and we also considered the demand for ES with the intention to apply the results to identify priority neighborhood for environmental actions

Research questions:

- Is the cooling capacity assessment methodology applicable in contexts with different data availability?
- How can its results be included in the simulation of an urban planning issue to address?
- How to apply a multiple-ES assessment in a data-poor context (Addis Abeba)?
- How to provide choose a priority neighborhood for action comparing ES supply and demand for ES? How should trade-offs be considered? What additional information may provide considering demand in the assessment?

Objective 4: develop guidance to support equitable distribution of ES in cities.

If the goal of plans and policies is to pursue human wellbeing, then average wellbeing cannot provide a sufficient evidence. Moreover, if wellbeing in cities depends also on natural capital, it is crucial to pursue equitable distribution of resources (and more specifically of ES) among citizens in a city. The adoption of ES assessments can provide a powerful tool to the assessment and pursue of equitable distribution of ES. However, in the practice, equitable distribution is assessed through general urban standards (e.g. availability of green per capita) or by applying ES assessments designed for purposes different from the pursue of equitable distribution of resources. Thus, we developed a methodology to assess equitable distribution of ES within a city.

Research questions:

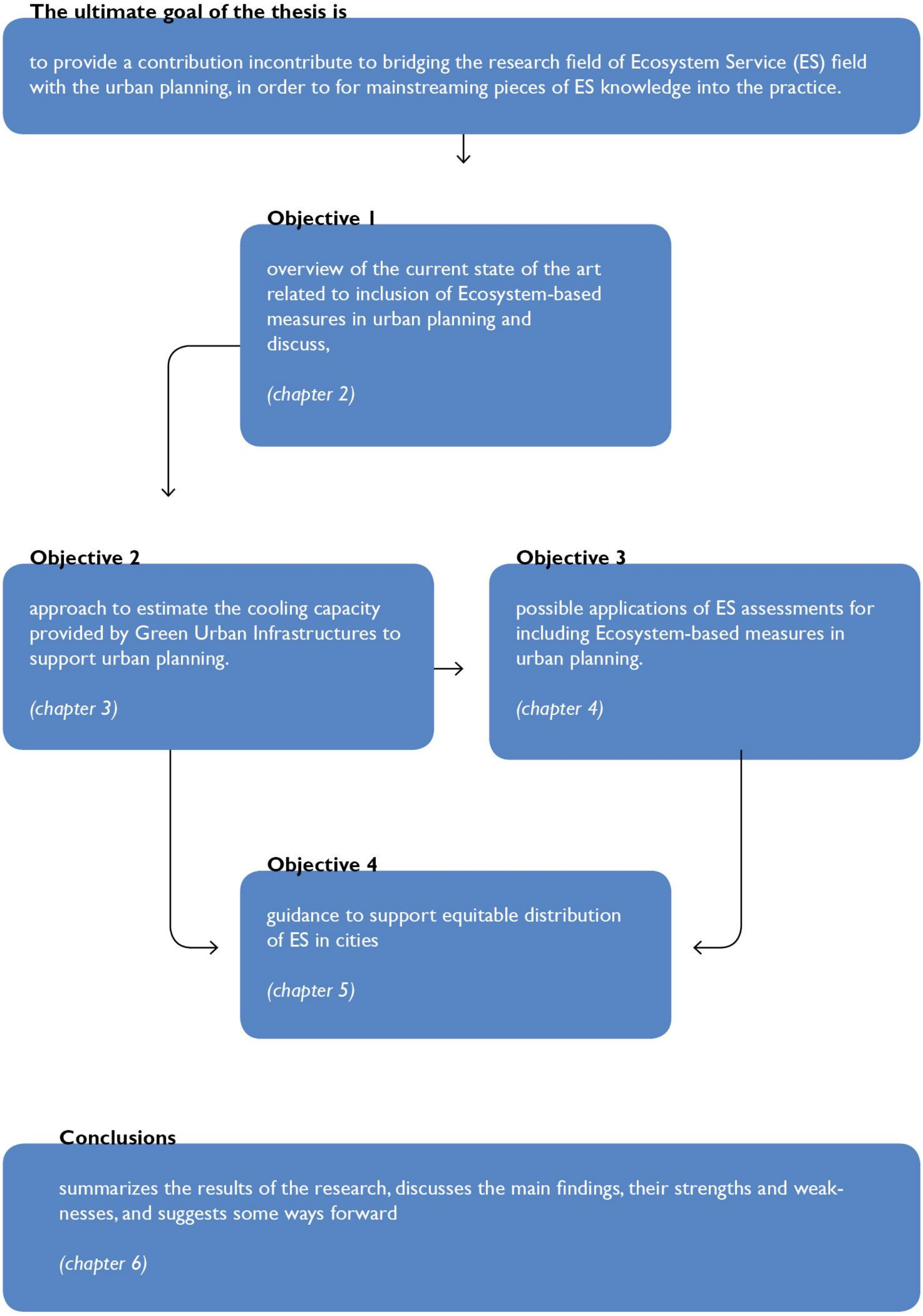
- Key elements to analyze equitable distribution of ES are: ES supply, access to ES and demand for ES. Which criteria should be followed to properly assess the key elements involved in the equitable distribution of ES?
- How to define the spatial distribution of these key elements for regulating ES –in particular, carbon storage, air pollution removal, cooling and noise reduction?

- Which is the ratio between availability of ES and ES demand in different parts of the city?
- To which extent this kind of ES assessment provides different information to planners and decision-makers compared to other ES assessments?

1.2 Outline of the thesis

The outline of the thesis is shown in Figure 1.1. and Figure 1.2 illustrates the main concepts driving the chapters.

Chapter 2 describes Ecosystem-based Adaptation in cities by providing an analysis of European urban climate adaptation plans (Objective 1). It develops a framework for analysing the inclusion of EbA in urban level climate planning, and applies it to a sample of climate adaptation plans in Europe. The framework consists of a classification of EbA measures, and a scoring system to evaluate how well they are reflected in different components of the plans. Chapter 3 takes stock of the results and conclusion of Chapter 2 and addresses one of the gaps identified in terms of knowledge available to inform decision makers to include EbA through the creation and restoration of Green Urban Infrastructures in urban planning. GUI contribute to reduce temperatures in cities and the associated health risks, by virtue of their cooling capacity. Thus, the aim of Chapter 2 is to propose an approach to estimate and map the cooling capacity provided by GUI to generate useful information to support planners and decision-makers (Objective 2). The approach is based on an analysis of the literature to identify the functions of GUI that are involved in providing cooling and the components of GUI that determine those functions, in order to provide an overall assessment of the cooling capacity of different GUI typologies. GUI. An illustrative case-study application in the city of Amsterdam shows the applicability of the approach. Chapter 4 presents two application of ES assessments to the urban planning practice through cases study, Trento in Italy- and Addis Abeba in Ethiopia, respectively (Objective 3). Chapter 5 represents an additional step in terms of proposing an ES assessment approaches to support because aims at defining how to build a ES assessments to analyse equitable distribution of ES in cities (Objective 4). With focus on regulating ES, Chapter 5 defines a set of criteria for analysing the three key elements of an equitable distribution of ES: ES supply, access to ES, and demand for ES. The proposed approach is applied to a case study to assess equitable distribution of regulating ES. In Chapter 5, to highlight differences and relevance of information, a comparison is made between our results and those from similar ES assessment approaches that however were not specifically designed to assess equitable distribution of ES. To conclude, Chapter 6 summarizes the results of the research, discusses the main findings, their strengths and weaknesses, and suggests some ways forward.



The ultimate goal of the thesis is

to provide a contribution incontribute to bridging the research field of Ecosystem Service (ES) field with the urban planning, in order to for mainstreaming pieces of ES knowledge into the practice.

Objective 1

overview of the current state of the art related to inclusion of Ecosystem-based measures in urban planning and discuss,

(chapter 2)

Objective 2

approach to estimate the cooling capacity provided by Green Urban Infrastructures to support urban planning.

(chapter 3)

Objective 3

possible applications of ES assessments for including Ecosystem-based measures in urban planning.

(chapter 4)

Objective 4

guidance to support equitable distribution of ES in cities

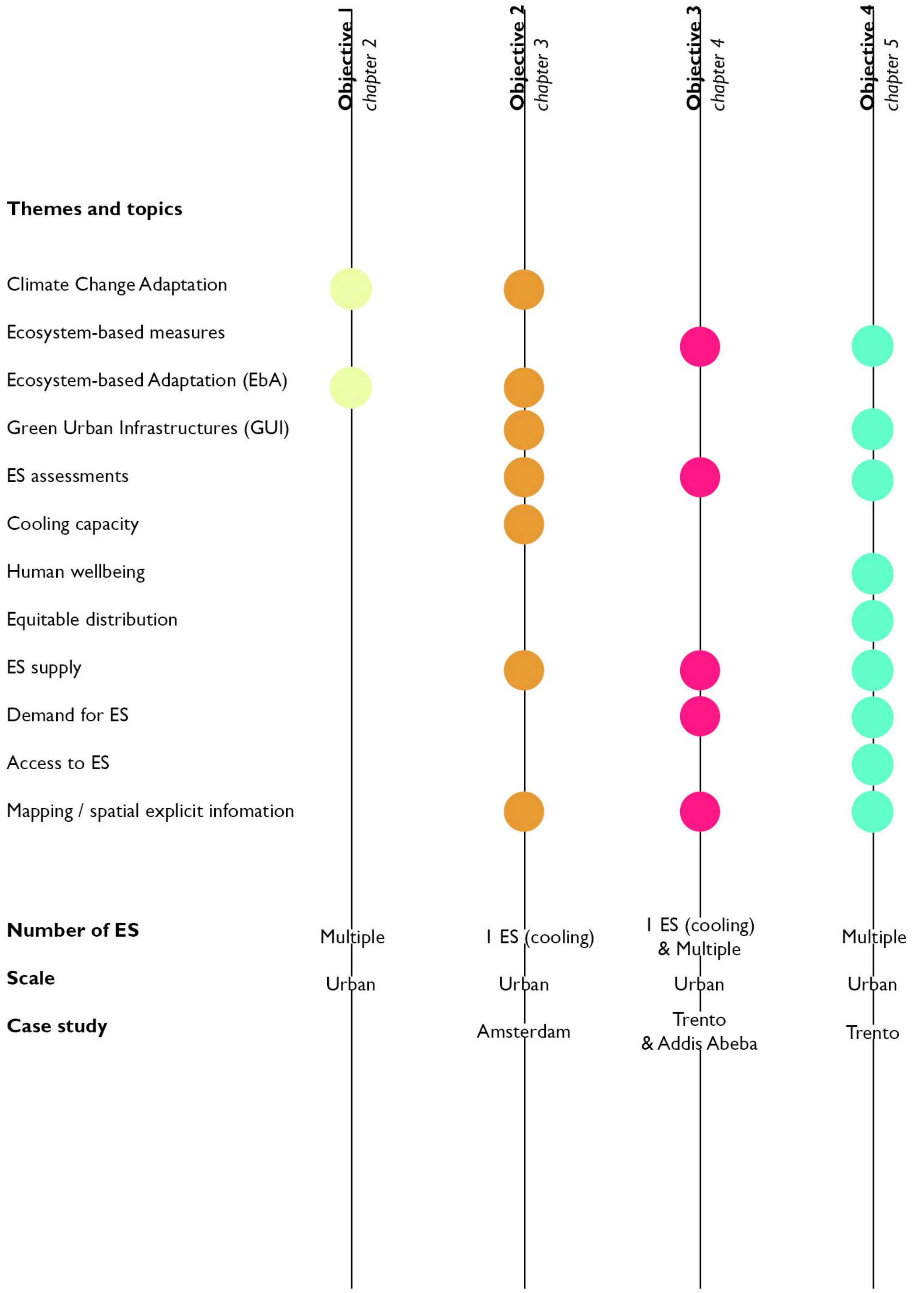
(chapter 5)

Conclusions

summarizes the results of the research, discusses the main findings, their strengths and weaknesses, and suggests some ways forward

(chapter 6)

Figure 1.1 Outline of the thesis



	Objective 1 *chapter 2*	**Objective 2** *chapter 3*	**Objective 3** *chapter 4*	**Objective 4** *chapter 5*
Themes and topics				
Climate Change Adaptation	●	●		
Ecosystem-based measures			●	●
Ecosystem-based Adaptation (EbA)	●	●		
Green Urban Infrastructures (GUI)		●		●
ES assessments		●	●	●
Cooling capacity		●		
Human wellbeing				●
Equitable distribution				●
ES supply		●	●	●
Demand for ES			●	●
Access to ES				●
Mapping / spatial explicit infomation		●	●	●
Number of ES	Multiple	1 ES (cooling)	1 ES (cooling) & Multiple	Multiple
Scale	Urban	Urban	Urban	Urban
Case study		Amsterdam	Trento & Addis Abeba	Trento

Figure 1.2 Themes and topics of the chapters

Chapter 2

Ecosystem-based adaptation in cities: an analysis of European urban climate adaptation plans*

2.1 Introduction

Climate change adaptation includes actions undertaken in natural or human systems in response to actual or expected climatic stimuli or their effects, in order to reduce harm or exploits benefits (IPCC, 2007). Although historically adaptation to climate change has received less attention than mitigation (Füssel, 2007), there has been a recent surge of interest in adaptation interventions, which are already a necessity in many contexts, particularly until greenhouse gases emissions will not be stabilized (Picketts et al.,2013).

Adaptation to climate change may be attained in different ways. One way that is attracting increasing attention is through ecosystem-based approaches. Ecosystem-based adaptation (EbA) is defined as the use of biodiversity and ecosystem services to help people to adapt to the adverse effects of climate change (CBD,2008). The concept of EbA was first introduced in the international policy arena by the United Nations Framework Conventionon Climate Change in 2008, and has been widely advocated by environmental organizations since then (Colls and Ash, 2009; TNC,2009). For example, restoring mangrove forest can contribute to dissipate the energy of storm surges, buffering human communities from floods and erosion (Erwin, 2009). Protecting groundwater recharge areas and floodplain can help to secure water resources and cope with droughts (TNC, 2009). Enhancing green infrastructures in urban areas can reduce the heat island effect, and the associated health risks (Lafortezza et al., 2013).

As opposed to more traditional infrastructure-based approaches (e.g., levees, sea walls,

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* The work presented in this chapter has been published as: Geneletti and Zardo, 2016. Geneletti, D., Zardo, L. Ecosystem-based adaptation in cities: An analysis of European urban climate adaptation plans. Land Use Policy, Volume 50, Pages 38–47 (2016)

irrigation systems), EbA offers the advantage of promoting “no regrets” interventions, and potentially delivering multiple economic, social and environmental co-benefits that go beyond climate adaptation (Jones et al., 2012). These co-benefits include, among others, biodiversity conservation through enhanced habitat conditions; climate mitigation through increased carbon sequestration; conservation of traditional knowledge, lively-hood and practices of local communities; improved recreation and tourism opportunities; enhanced food security (Demuzere et al.,2014; Naumann et al., 2011; Vignola et al., 2009; Munang et al.,2013b,c). Even though EbA approaches generally lack quantitative estimates of the adaptation potential (Jones et al., 2012), there is increasing evidence that they can provide flexible, cost- effective and broadly applicable alternatives to cope with the magnitude, speed and uncertainty of climate change (Munang et al., 2013a). For these reasons, EbA has rapidly become an important aspect of the international climate policy framework. As an example, the European Union recent climate adaptation strategy (EC, 2013) explicitly encourages the adoption of green infrastructure and ecosystem-based approaches to adaptation.

Cities are particularly vulnerable to climate change, due to the large and growing urban population worldwide and the complex patterns of economic assets, infrastructures and services that characterize them. Hence, achieving climate adaptation in urban areas is pivotal for sustainable development, as shown by growing actions undertaken by cities to pursue adaptation (Rosenzweig et al., 2010), as well as guidance documents produced to assist in this endeavor(e.g, ICLEI, 2010). Picketts et al. (2013) suggested that climate adaptation “is well suited to local levels of governments, as citizens can participate in creating targeted adaptation strategies that address the important regional impacts, and these strategies will provide tangible benefits to local residents”. Along the same lines, Meashamet al. (2011) consider planning at municipal level as a key avenue to mainstream adaptation actions.

EbA can play an important role in urban contexts and help to cope with increased temperature, flood events and water scarcity, by reducing soil sealing, mitigating heat island effect and enhancing water storage capacity in urban watersheds (Muller et al., 2013;Grimsditch, 2011; Gill et al., 2007). EbA in cities include approaches based on the design and improvement of green and blue infrastructures (e.g., urban parks, green roofs and facades, tree planting, rivers, ponds), as well as other types of interventions that use ecosystem functions to provide some form of adaptation to cli-mate risks (e.g., measures to reduce soil imperviousness) (Robertset al., 2012; Doswald and Osti, 2011). In cities, most ecosystems are “urban ecosystems”, i.e., ecosystems where the built infrastructure covers a large proportion of the land surface, or those in which people live at high densities (Pickett et al., 2001; Savard et al., 2000).Urban ecosystems include all green and blue spaces in urban areas, and typically have a low level of naturalness, being heavily man-aged or entirely artificial (Gómez-Baggethun and Barton, 2013).Green roofs are an example of urban ecosystems almost exclusively determined by humans and that require regular maintenance(Oberndorfer et al., 2007). The term EbA measures is commonly used also in cities to refer to the use of urban ecosystems to pro-vide services that help to adapt to climate change (e.g., Zandersenet al., 2014; Doswald et al., 2014; Munroe et al., 2012; Doswald and Osti, 2011).

The recent literature has addressed the potential role of EbA in cities (Müller et al., 2013; Bowler et al., 2010; Berndtsson, 2010).In particular, Demuzere et al., (2014) presented a comprehensive analysis of the available empirical evidence about the contribution of green infrastructures to climate change adaptation in urban areas. Nevertheless, the concept of EbA is still relatively new for cities, and little evidence is available on the inclusion of EbA measures in actual urban plans and policies (Wamsler et al., 2014).Urban planning, at least in more industrialized countries, has been increasingly addressing climate adaptation strategies and actions, as shown by recent reviews of planning documents undertaken for undertaken for cities in Europe (Reckien et al., 2014), the UK (Heidrich, 2013),Australia (Baker et al., 2012) and North America (Zimmerman and Farris, 2011). However, none of these papers address specifically EbA.The grey literature contains several collections of experiences, but they focus either on urban adaptation in general, with little emphasis on ecosystem-based approaches (EEA, 2012), or on EbA, with little emphasis on urban areas (Doswald and Osti, 2011;Naumann et al., 2011; Andrade Pérez et al., 2010). The majority of the EbA case studies presented in the latter reports is related to natural areas, coastal zones, agriculture and forestry. An exception is represented by the work of Kazmierczak and Carter (2010), which compiles a database of case studies to showcase EbA approaches in cities. However, these case studies do not specifically relate to planning, but to a broader set of initiatives, including for example incentive schemes, physical infrastructure delivery, guidance documents, etc. In conclusion, the extent to which EbA approaches are actually included in planning at the urban level is largely notdocumented. This paper addresses this gap by developing a classification of EbA and a scoring system to analyze the treatment of EbA in urban climate adaptation planning, and apply it to a sample of plans in Europe. Specifically, the paper aims at answering questions related to:

- The types of EbA measures that are included in climate adaptation plans (What are the most common ones? To what climate change impact do they aim to respond?)
- The extent to which EbA measures are considered and described in climate adaptation plans (In what parts of the planning documents are EbA measures present? How well and how consistently are they treated?)

The ultimate purpose of the paper is to provide an overview of the current state of the art related to the inclusion of EbA in urban planning, and use it to identify and discuss the main shortcoming and propose possible solutions. First, we describe the review framework, which includes the identification of EbA measures that are relevant for urban adaptation. We then present the sample of planning documents, and the method that was used to extract information relevant to the study. Afterwards, we present the results of the evaluation. Finally, we discuss the main findings and conclude by providing recommendations to improve future practice in urban planning.

2.2 Methods

2.2.1 Classification of EbA measures

As a first step in our study, we identified and classified possible measures for EbA that are relevant for urban areas. Many examples and descriptions of EbA measures are present in the literature (Doswald et al., 2014; Zandersen et al., 2014; Jones et al., 2012; Doswald and Osti, 2011; TNC, 2009). However, to the best of our knowledge, a comprehensive classification of typologies of EbA measures that can be employed in urban areas has not been developed. Most studies focus on EbA in agriculture and forest areas (e.g., Vignola et al., 2009) or anyway do not provide a classification of different EbA typologies. The closest attempt to produce a list of possible EbA in urban contexts was found in EEA (2012). Here, different types of measures are associated to the climate change impacts they aim at reducing, i.e., heat, flooding and water scarcity. These three impacts reflect the expected effects of the current projections of average climate change: the increase in duration, frequency and/or intensity of heat waves, extreme precipitation events and droughts (Barriopedro et al., 2011; Giorgi et al., 2011;Hoerling et al., 2012).

The list proposed by EEA (2012) was revised and integrated with other typologies found in the literature. This resulted in the classification presented in Table 2.1, where definition, rationale and supporting references are provided for each measure. Measures are associated to the climate change impact they are meant to reduce, even though it is recognized that synergies occur. For example, green roofs may contribute to reduce runoff water quantity (Czemiel Berndtsson, 2010), in addition to building cooling. The EbA measures play at different spatial scales, ranging from building-scale interventions (e.g., green roofs and walls) to urban-scale interventions (e.g., city-wide green corridors). Despite their difference in scale, the identified measures are all within the scope of urban plans, hence they can be (at least partly) implemented by actions proposed in planning instruments. Measures such as river renaturalization, in most cases, cannot be handled within the border of a city alone. However, urban plans have the possibility to implement these interventions (at least for the urban sector of rivers), as well as to promote coordination with other planning levels (e.g., regional planning, river basin planning). For this reason, these measures have been included in the proposed classification of EbA measures relevant for urban areas.

2.2.2 Selection of the sample of plans

There are many planning instruments that address climate change adaptation at the local level. We use the term ‘climate adaptation plan’ to refer in general to plans that include strategies to reduce vulnerability to climate change in cities, even though the actual name of the plan might be different. At European level, there is little information on the range of plans being developed under the rubric of climate action planning, and to our knowledge there is no central database or agency collecting this information. For this reason, we decided to focus on a sample of cities considered active in climate change adaptation, by referring to the “C-40” initiative (http://www.c40.org). The C-40 was established in 2005 as a network of large cities worldwide that are taking action to reduce greenhouse gas emissions and to face climate risks. This sample offers the advantage of providing information on different initiatives undertaken by cities that have been particularly active in climate adaptation strategies. This is consistent with the purpose of this study, which is to offer an overview of the extent to which EbA measures are included in planning instruments of cities engaged in climate actions, as opposed to evaluating the performance of different cities or geographical regions. Among the cities of the C-40 database, we selected the ones belonging to Member States of the European Union. This resulted in a sample of 14 cities, namely Amsterdam, Athens, Barcelona, Berlin, Copenhagen, Heidelberg, London, Madrid, Milan, Paris, Roma, Rotterdam, Stockholm, Venice and Warsaw. A cross-check with European-level data sets on heat, floods and water scarcity published by the European Environmental Agency1revealed an even presence of climate change challenges in the city sample: seven of the selected cities are located in regions affected by heat waves, seven by floods and six by water scarcity. We then gathered all the urban climate change responses in the form of planning documents approved by the relevant municipal authority, and available on the internet. This resulted in the list of planning documents listed in Table 2.2. As can be seen, all the selected cities have approved a Sustainable Energy Action Plan (SEAP). The SEAP is the key planning instrument provided for by the “Covenant of Mayor”, a local-level initiative supported by the European Commission that promotes the involvement of local authorities in responding to climate change. Even though originally SEAP were to address mostly measures for CO2emission reduction, energy efficiency and renewable energy, they have expanded their scope to include more broadly all climate-related measures (Zanonand Verones, 2013). As shown in Table 2.2, some cities approved additional plans related to climate change, which were also included in our analysis.

2.2.3 Analysis of the content of the plans

Prior to the analysis, the content of the plans was divided into four components: information base; vision and objectives; actions; implementation. These components represent thematically different parts of the plans. The information base includes the analysis of current conditions and future trends (typically presented in the introductory parts of the planning documents), which is performed in order to provide a basis for the subsequent development of the plan's objectives and actions. Vision and objectives include the statement of the ambition and of the general and specific objectives that a plan intends to achieve. Actions include all the decisions, strategies and policies that the plan propose, in order to achieve its objectives. Finally, implementation refer to all measures (including budget-related ones) proposed to ensure that actions are carried out. This classification of plan components is a modified version of the one proposed by Baker et al. (2012), which comprises also a fifth component: options and priorities, i.e., the development and prioritization of alternative solutions. This component was not included here because largely missing from the planning documents considered in this study. The proposed four-component approach is consistent (even though it uses a different terminology) with the one used by Heidrich et al. (2013) to review adaptation and mitigation plans in the UK.

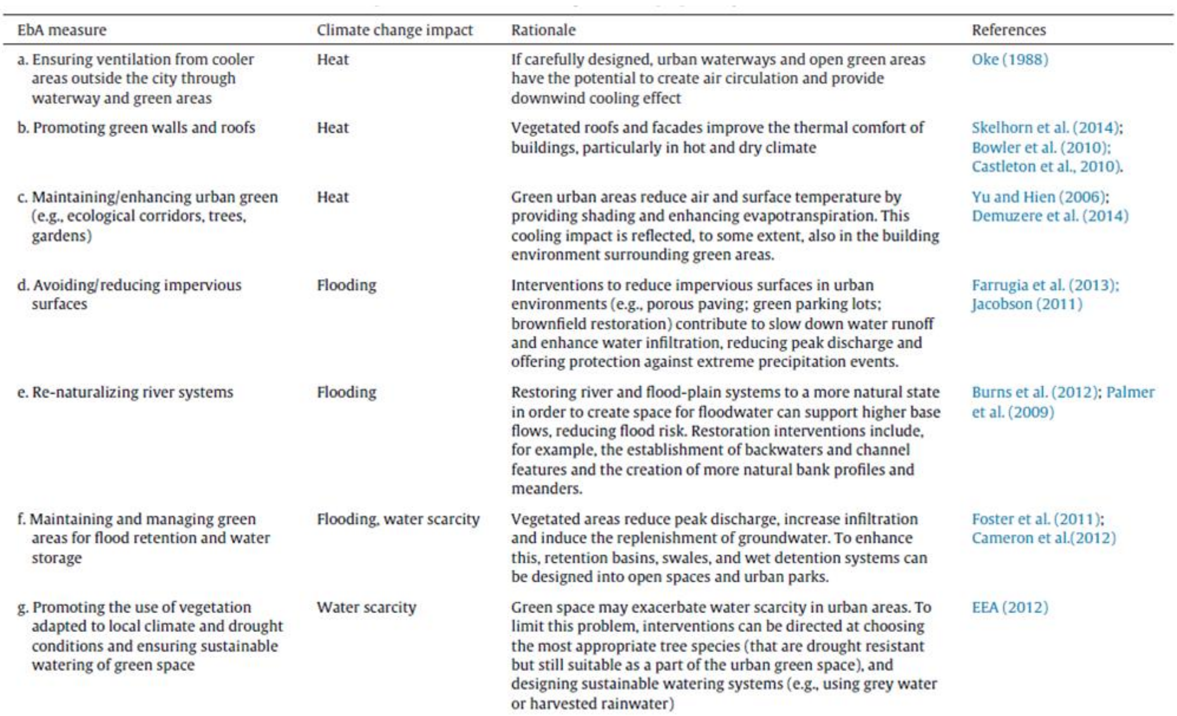
A direct content analysis (Hsieh and Shannon, 2005) was per-formed, by reading all the documents associated to the selected plans, and identifying – for each of the four components – the con-tent related to EbA measures, using the classification presented in Table 2.1. This approach was preferred to a keyword-based analysis, given that there is not yet a well-established terminology in this field, and plans use a wide range of different wording to refer to concepts related to EbA, and to ecosystem services in general (Braat and de Groot, 2012). Hence, we searched for the presence of the different measures, irrespective of whether the plan used the term "EbA" or not to describe them. By breaking down the analysis in the four plan components, it was possible to test also the overall consistency of the plan with respect to EbA-related issues, i.e. the extent to which the EbA-related analysis contained in the information base provide an appropriate factual basis for developing objectives, which in turn are linked to suitable actions, and implementation proposals (Bassett and Shandas, 2010).The content analysis followed a two-step process. First, the presence of the different EbA measures in each plan component was searched, by using the following guiding questions:

- Information base: Does it contain data/statements/analyses that show awareness about EbA?
- Vision and objectives: Are there objectives associated to the development/enhancement of EbA measures?
- Actions: Are there actions aimed at developing/enhancing EbA measures?
- Implementation: Do the implementation provisions include reference to EbA measures?

Second, whenever the answer to the previous questions was positive, the content was further analysed in order to assess the extent to which EbA measures were addressed, by using the four-level scoring system presented in Table 2.3. The assigned scores were cross-checked by all authors of this research. Finally, an average score was obtained for each type of EbA measure by computing the average value obtained by that measure in all the plans where the measure is found, and for all plan components.

In this study we reviewed the English translation of the planning documents, which was always available except for the plans of Milan, Venice and Rome, for which we reviewed the original documents in Italian. Fearing that translations might be reduced versions of the original plans (and omit important details),we checked also the original documents, whenever we had the required language skills, i.e. for the plans written in Spanish and French. These checks showed that the translations were accurate and complete. Based on this, we concluded that the English translations are adequate for the purposes of this study.

Table 2.1 The classification of EbA measures for urban areas adopted in this research



EbA measure	Climate change impact	Rationale	References
a. Ensuring ventilation from cooler areas outside the city through waterway and green areas	Heat	If carefully designed, urban waterways and open green areas have the potential to create air circulation and provide downwind cooling effect	Oke (1988)
b. Promoting green walls and roofs	Heat	Vegetated roofs and facades improve the thermal comfort of buildings, particularly in hot and dry climate	Skelhorn et al. (2014); Bowler et al. (2010); Castleton et al., 2010).
c. Maintaining/enhancing urban green (e.g., ecological corridors, trees, gardens)	Heat	Green urban areas reduce air and surface temperature by providing shading and enhancing evapotranspiration. This cooling impact is reflected, to some extent, also in the building environment surrounding green areas.	Yu and Hien (2006); Demuzere et al. (2014)
d. Avoiding/reducing impervious surfaces	Flooding	Interventions to reduce impervious surfaces in urban environments (e.g., porous paving; green parking lots; brownfield restoration) contribute to slow down water runoff and enhance water infiltration, reducing peak discharge and offering protection against extreme precipitation events.	Farrugia et al. (2013); Jacobson (2011)
e. Re-naturalizing river systems	Flooding	Restoring river and flood-plain systems to a more natural state in order to create space for floodwater can support higher base flows, reducing flood risk. Restoration interventions include, for example, the establishment of backwaters and channel features and the creation of more natural bank profiles and meanders.	Burns et al. (2012); Palmer et al. (2009)
f. Maintaining and managing green areas for flood retention and water storage	Flooding, water scarcity	Vegetated areas reduce peak discharge, increase infiltration and induce the replenishment of groundwater. To enhance this, retention basins, swales, and wet detention systems can be designed into open spaces and urban parks.	Foster et al. (2011); Cameron et al.(2012)
g. Promoting the use of vegetation adapted to local climate and drought conditions and ensuring sustainable watering of green space	Water scarcity	Green space may exacerbate water scarcity in urban areas. To limit this problem, interventions can be directed at choosing the most appropriate tree species (that are drought resistant but still suitable as a part of the urban green space), and designing sustainable watering systems (e.g., using grey water or harvested rainwater)	EEA (2012)

2.3 Results

2.3.1 What EbA measures are included in the plans and how well are they addressed?

Consistently with the purpose of the study, the results are not presented and discussed in terms of the quality of the individual plans, but they are broken down by EbA measure and by plan components. A total of 44 EbA measures were found in the selected plans. Figure. 2.1 illustrates the breakdown in the seven types described in Table 2.1. As can be seen, measures c (maintaining/enhancing urban green) and f (maintaining and managing green areas for flood retention and water storage) are the most common ones, and are found in 85% of the selected plans. Examples of measures c include efforts to increase green areas and neighbourhood gardens (Paris),proposals for enhancing the connectivity among existing green areas through the design of green corridors and rings (Milan) and the use of plants to provide shade in new industrial estates (Amsterdam). Measures f consist, for example, in the creation of new wetland areas and ponds (Berlin), and the design of green spaces to store rainwater in the event of torrential rain (Copenhagen).

Measure b (Promoting green walls and roofs) is found in 57%of the plans. For example, Paris's plan contains provisions for the establishment of roof and wall gardens (measure b), including the identification of priority spots for this type of green infrastructures. Measure e (re-naturalizing river systems) is found in 29%of the plans. In Madrid, for example, this consisted in a series of bank improvements projects aimed are reducing flood hazard and expanding riverside public space. Measures a, d and g (respectively, ensuring ventilation, avoiding/reducing impervious surfaces, and promoting climate-adapted vegetation and sustainable watering) are less common, and found only in 14–21% of the plans. For example, concerning measure a, cold air networks to ensure ventilation and prevent over-heating are mentioned in Copenhagen's plan, whereas Madrid's provides for the promotion of ecobarrios where ventilation will be one of the factors considered in the design of greening interventions. Berlin's plan attains the reduction of impervious surfaces (measure d) through renovation projects for buildings and school playgrounds that include interventions to improve soil permeability and in situ infiltration. Finally, concerning measure g, Venice's plan promotes the use of autochthonous species adapted to the local climate, and Madrid's contains detailed guidelines for "sustainable gardens" with recommendations for the selection of plant species and sustainable watering systems. The results of the application of the scoring systems (presented in Table 2.3) were used to compute an average score for each type of EbA measure (Fig. 2.2), representing the average value obtained by the measure in all the plans where the it is found, and for all plan components. As can be seen, the average score ranges from1.1 (achieved by measures a and g) to 2.4 (measures e). Measures c and f, which are the most frequently found, are also the ones with the highest scores, together with action e.

2.3.2 How are EbA measures reflected within plan components?

Figure. 2.3 shows in which plan components (see Section 2.3) EbA measures are reflected. 91% of the measures are present in the vision and objectives component. This means that, when a plan includes an EbA measure, this is very often listed as (part of) one of the objectives that the plan intends to achieve. For example, Paris's plan objectives include the development of a multi-year scheme to pro-mote roof gardens. 91% of the EbA measures are addressed in the actions component, meaning that the plans include specific policies or activities to attain them. For example, Milan's plan includes a series of linear greening interventions along canal banks, roads, biking routes, etc. The information base component of the plans contains data relevant to EbA measures only in 79% of the cases. That is, 21% of the measures found in the plans are not supported by any baseline information or analysis. Even when baseline information is present, this consists mostly of general statements and descriptions. For example, Berlin's plan contains descriptions of how energy efficiency of buildings or industry could be usefully combined with projects to support sustainable local water management systems, by increasing the permeability of soil and planting vegetation.

Table 2.2 List of the planning documents reviewed in this research.

City	Name of the plan	Year	Source
Amsterdam	Amsterdam: a different energy (SEAP)	2010	http://mycovenant.eumayors.eu/
	Amsterdam definitely sustainable	2011	http://www.nieuwamsterdamsklimaat.nl/
	New Amsterdam climate	2010	http://mycovenant.eumayors.eu/
	Outspokenly sustainable-perspective 2014	2009	http://www.nieuwamsterdamsklimaat.nl/
	Structure vision for Amsterdam 2014	2008	http://www.nieuwamsterdamsklimaat.nl/
Barcelona	The energy, climate change and air quality plan for Barcelona (SEAP)	2011	http://mycovenant.eumayors.eu/
Berlin	Berlin environmental relief programme (10 years) (SEAP)	2011	http://mycovenant.eumayors.eu/http://http://www.berlin.de/
Copenhagen	Copenhagen climate adaptation plan (SEAP)	2011	http://mycovenant.eumayors.eu/ http://www.kk.dk/
Heidelberg	Climate protection commitment Heildelberg (SEAP)	2010	http://mycovenant.eumayors.eu/
London	Delivering London's energy future (SEAP)	2010	http://mycovenant.eumayors.eu/
	The London Plan: spatial development strategy for a greater London	2008	http://www.london.gov.uk
Madrid	Plan de uso sostenible de la energia y prevencion de cambio climatico (SEAP)	2008	http://mycovenant.eumayors.eu/
Milano	Piano per l'energia sostenibile ed il clima (SEAP)	2009	http://mycovenant.eumayors.eu/
Paris	Paris climate protection plan (SEAP)	2004	http://mycovenant.eumayors.eu/
Roma	Piano d'azione per l'energia sostenibile per la città di Roma (SEAP)	2010	http://mycovenant.eumayors.eu/
Rotterdam	Investing in sustainable growth, Rotterdam programme on (SEAP)	2010	http://mycovenant.eumayors.eu/
	Rotterdam climate city, mitigation action programme	2010	http://www.rotterdamclimateinitiative.nl/
	The new Rotterdam, Rotterdam climate initiative	2009	http://www.rotterdamclimateinitiative.nl/
Stockholm	Stockholm action plan for climate and energy (SEAP)	2012	http://mycovenant.eumayors.eu/ http://www.stockholm.se/
	Stockholm climate initiative	2010	http://www.stockholm.se/
Venezia	Piano d'azione per l'energia sostenibile (SEAP)	2013	http://mycovenant.eumayors.eu/
Warsaw	Sustainable action plan for energy Warsaw (SEAP)	2011	http://mycovenant.eumayors.eu/

Table 2.3 Scoring system used to evaluate the plan component.

Score	Information base	Vision and objectives	Actions	Implementation
0	No evidence of information related to EbA measures	No evidence of objectives related to EbA measures	No evidence of EbA measures	No evidence of implementation provisions related to EbA measures
1	Acknowledges EbA measures only generally (not in connection to specific climate change issues)	Mentions EbA-related objectives, but lacks further definition	Mentions EbA measures, but lacks further definition	Mentions implementation provisions related to EbA measures, but lacks further definition
2	Acknowledges EbA measures in the context of specific climate change issues	Includes EbA measures in the objectives and provides some details on their specific content and how to pursue them	Includes EbA measures in the actions and provides some details on their application and activities	Includes EbA-related implementation provisions and provides some details on their application
3	Acknowledges EbA measures and describes (at least qualitatively) the potential climate changeadaptation effects	Includes EbA measures in the objectives, provides details on their content, and describes links with related planning and policy processes at the local/regional level	Includes EbA measures in the actions, provides information on their application and activities, including locally-specific details	Includes EbA-related implementation provisions and provides information on their application, including details on budget, responsible bodies, etc

The implementation component of the plans performs even more poorly: references to EbA measures are found in only 52% of the cases. Therefore, about half of EbA measures are not associated to any action to ensure that they are carried out. When information about implementation measures are present, this consists mainly of budget-related details, as for example in the case of Madrid’s plan (where each action is linked to a plan of implementation and budget), and Rotterdam’s, where there are indications about green roofs subsidies. In order to assess how well EbA measures are reflected withinthe different plan components, we computed the average scoreobtained by all EbA measures that are found in each of the four components. For example, out of the 44 EbA measures, 35 are presenting the information base component of the selected plans. The average score represents the average of the scores obtained by these35 EbA according to the scoring system presented in Table 2.3 (second column: information base). The results (Fig. 2.3) show that actions component scored the highest (average score: 2.8), followed by the implementation (2.5), the vision and objectives (2.2) and the information base (1.8). Concerning the good performance of actions, examples include London’s plan, which describes in detail the actions and associated sub-actions, specifies the responsible bodies and identify links with other plans and policies. Similarly, Madrid’s plan provides action fact-sheets, with the identification of responsible bodies and associated budget. The poorer scores of the visions and objectives component are due to the fact that their description tend to be very general. The information base typically lacks details on the links between measures and climate-related issues, particularly concerning the results expected from the apple-cation of the measure. Finally, Figure. 2.4 provides a visual overview of the distribution of information on the identified EbA measures across plan components. This figure helps to understand how consistency EbA measures are treated across the different plan components, and where the gaps are. The figure shows that the 44 EbA measures identified in the plans can be grouped in six categories:

- Measures addressed in all the four plan components, from the information base through the implementation. This is obviously the most desirable situation, but occurred only for 45.5% of the EbA measures. In all other cases, at least one component is lacking;- Measures addressed in the first three components of the plans, but not in the implementation part. This occurs for 22.7% of the EbA measures;- Measures addressed only in the vision and objectives and actions with no links to the information base or implementation (13.6%);- Measures addressed only in the information base and vision and objectives, with no follow-up in the rest of the plan (6.8%);- Measures addressed in the information base only, with no follow-up in the rest of the plan (2.3%)- Measures addressed in the vision and objectives, actions and implementation components, with no links to the information base (2.3%).

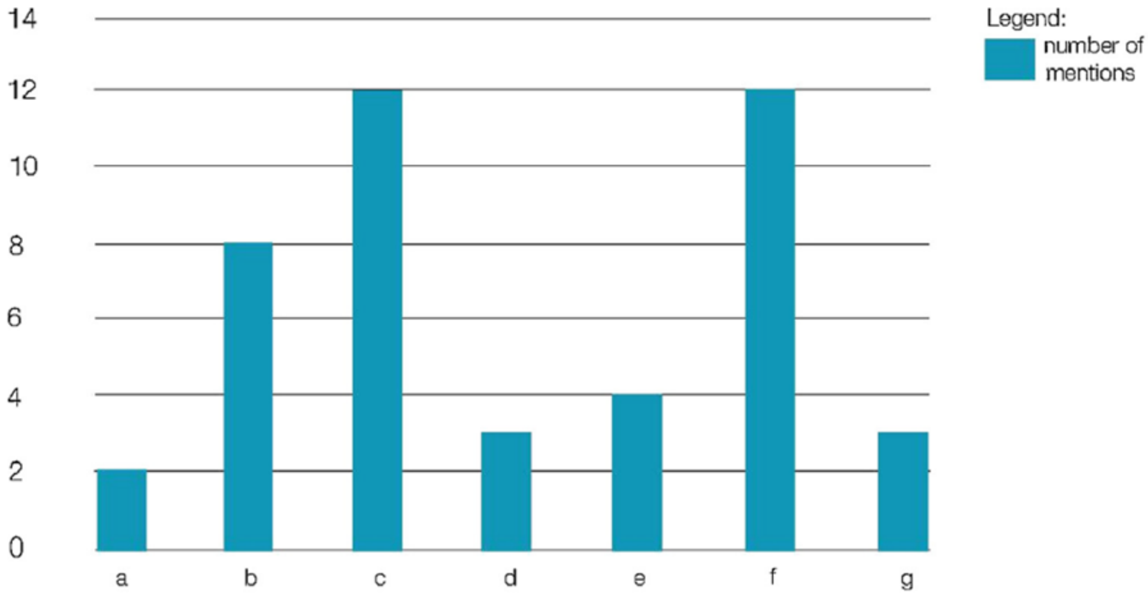


Figure 2.1 Number of mentions of the seven types of EbA measures (see legend in Table 2.1) in the sample of plans.

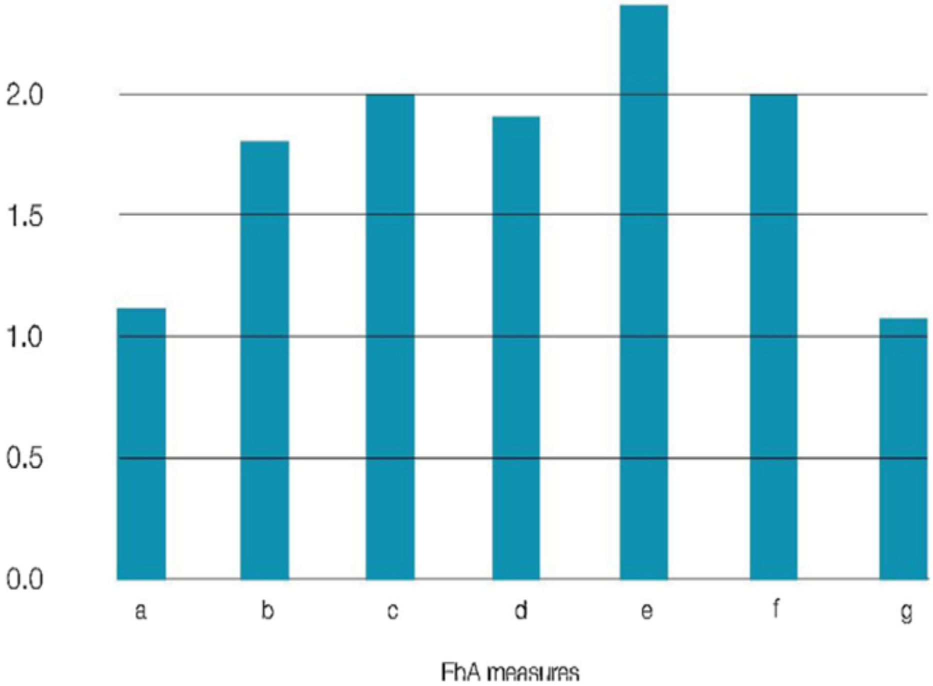


Figure 2.2 Average scores of the seven types of EbA measures

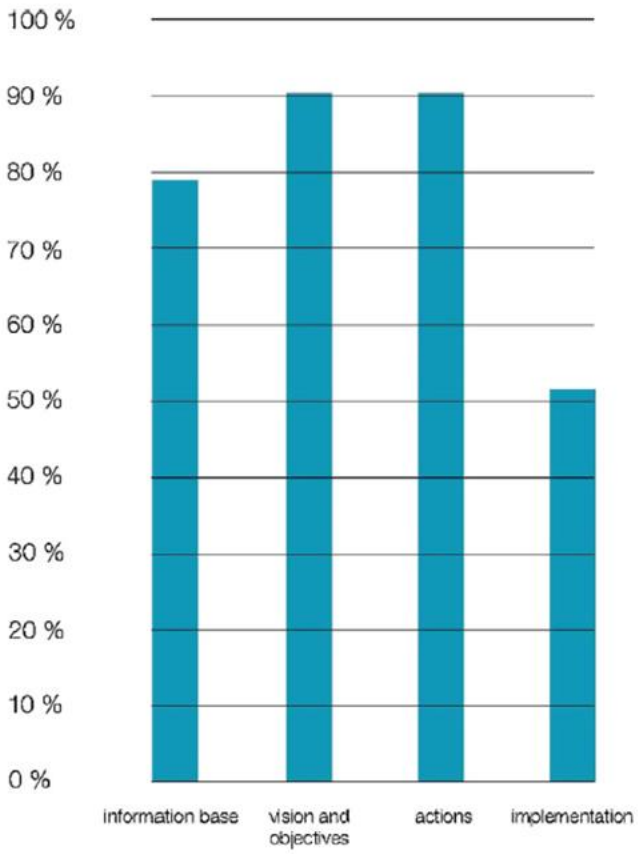


Figure 2.3 Frequency of presence of information about the 44 EbA measures in the different plan component.

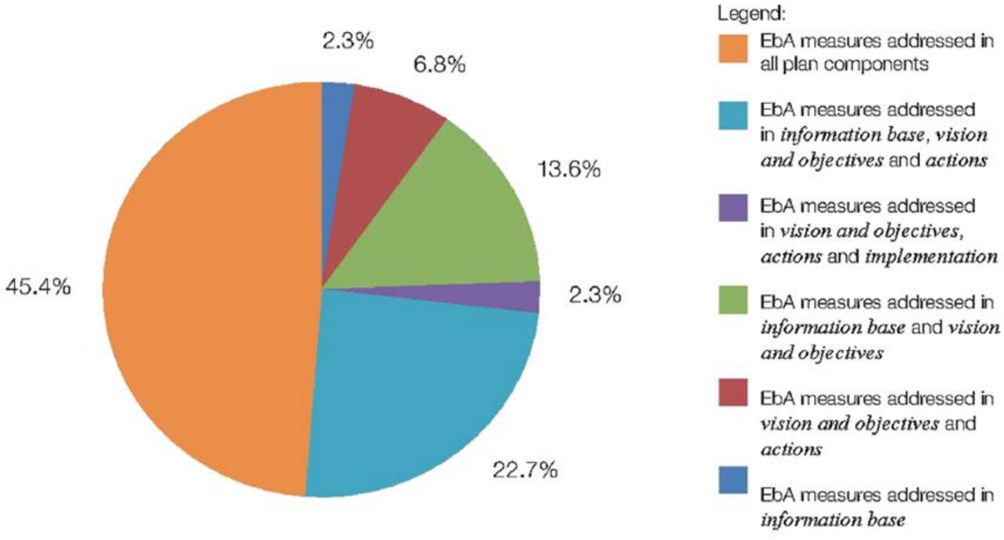


Figure 2.4 Distribution of information on the identified EbA measures across the plan components (see text for further explanation).

2.4 Discussion

The recent scientific literature has shown a growing interest in analysing the content of climate adaptation plans at the local level, in order to assess their quality and effectiveness and to formulate suggestions for future improvement (Kumar and Geneletti, 2015; Reckien et al., 2014; Heidrich et al., 2013; Bakeret al., 2012; Tang et al., 2010). This in recognition of the important role played by local administrations in addressing climate change challenges, being often ahead of national legislation and actions (Rosenwein et al., 2010). However, to the best of our knowledge, there are no published studies that address the combination of these two issues, i.e., the actual inclusion of EbA measures in urban climate adaptation plans. More in general, little evidence is avail-able on the up-take of EbA measures in urban areas, given that most of the published work focuses on natural areas, agriculture and forestry (Doswald and Osti, 2011). This research contributed to fill this gap, by shedding some light on what EbA measures are most commonly found in plans, how well they are addressed, and how consistently throughout the different plan components.

Measures c and f are the most common ones, showing that there is strong awareness of the role that green areas play in addressing climate change challenges, both in terms of mitigating heat waves (measure c) and preventing floods (measure f). The frequency of these measures is perhaps not surprising giving that they resulting the enhancement of green areas, which is a typical objective that planners pursue to improve the urban space for a variety of purposes that go beyond climate change adaptation (e.g., providing recreation opportunities, improving air quality) (Tzoulas et al.,2007). So, their frequency could be explained by the fact that these measures rely on actions that are part of the standard portfolio that planners have been employing for decades. However, a critical issue that we detected is that the proposal of these EbA measures in the plans is rarely backed-up by specific information on the expected contribution in terms of climate change adaptation, as well as the target beneficiaries. That is, in the revised plans, the enhancement of green areas to reduce heat or to prevent floods is typically proposed as a general measure that will do some good, without providing details and justification for critical decisions, such as the design and the location of these interventions, and the distribution and vulnerability of the expected beneficiaries. These issues play a key role in determining the effectiveness of the measures (Kleerekoper et al., 2012; Kazmierczak, 2012).

Green walls and green roofs (measure b) are found in more than half of the cities. These measures are well covered by the literature, which offers ample debate on the effectiveness of vegetated roofs and facades to improve the thermal comfort of buildings, providing data for different climate zones and recommendations for implementation (Santamouris, 2014; Cook-Patton and Bauerle, 2012).The relatively low presence of measure d is somehow surprising, especially considering that EbA measures to reduce impervious surfaces include interventions at the local level, which are often relatively cheap and do not pose particular challenges in terms of coordination with other policies or plans (Carmon and Shamir,2010). Therefore, they are quite straightforward to include in cli-mate adaptation plans, and the fact that they are mentioned only in less than one third of the plans suggest that there is still need to increase awareness in local administration officers and planners. This finding is consistent with previous research (Brabec, 2009), showing that the careful design of impervious areas is largely over-looked.

Measure a is the least frequently encountered measure. One reason may be that the effectiveness of this measure is related to the urban morphology more in general. Elements such as building footprint, density and height and street layout have a strong influence on urban ventilation corridors (Wong et al., 2010). Hence, the design of urban waterways and open green areas that create air circulation needs to be undertaken jointly with other actions related to the built environment that go beyond the content of climate adaptation plans. This hampers the possibility for climate adaptation plans to advance this type of EbA measures, requiring strong coordination with other planning instruments, such as urban plans. Measure g was also rarely found in plans, but this may be explained by the fact that it encompasses a more limited set of actions, which may be relevant only in specific climate conditions. Finally, the analysis revealed that all the cities affected by water scarcity included in their plans at least one EbA measure to cope with this climate change challenge. The same occurred with cities affected by floods. Concerning heat waves, all but one city proposed EbA measures to cope with it. This suggests that there is a general awareness about the portfolio of possible EbA measures, and the capability to select those that better fit the needs of a particular contexts. The main critical point resides in the depth of the analyses performed to support and design a specific measure, as described next.

By tracking the treatment of EbA measures in the four plan components, it was possible to test also the overall consistency of the plan, i.e. the extent to which the EbA-related analysis contained in the information base provides an appropriate factual basis for developing objectives, which in turn are linked to suitable actions, and finally to implementation proposals. Our analysis reveals that the most frequent missing link involves the implementation component. This component is often absent, with many cases of EbA measures that are addressed throughout the plan, but in the implementation part. Even when present, this component has the poorest performance, as the content tends to be vague with few tangible elements that may be used to track how planners envisage to implement the measures. This problem was also found by other studies of climate adaptation plans, such as Tang et al. (2010)’which concluded that implementation provisions were associated to relatively few strategies.

One final note concerning possible future developments of this research. This study proposed a classification for EbA measures and scoring system to assess the extent to which they are included in plans. Further work can be done to refine and improve this classification, which could be ultimately employed as a basis for the development of EbA reference manuals and handbooks for planners. The relatively small size of the sample of cities, and the way it was selected (i.e., by looking at cities that are already active in climate adaption), do not permit to reach conclusions on the “state of preparedness” (Heidrich et al., 2013) of different cities or regions in regions in Europe, with respect to the adoption of EbA measures in their cli-mate adaptation plans. As acknowledged in Section 2, the choice of the sample is biased in that it includes cities that represent positive examples of climate adaptation, and that often have a consolidated past in sustainable planning. This is consistent with the objective of the study, which was to assess the inclusion of EbA measures in cities engaged in climate actions, in order to understand what are the most common measures and how they are developed in their planning instruments. A follow-up study could employ the same approach to investigate a larger sample of cities, selected in a way to be representative of the conditions in different geographical areas. For example, future studies could focus on individual countries, and select cities representative of socio-economic and demographic conditions across those countries. Another possible follow-up of this work could shift the focus from climate adaptation plans to other types of plans at the urban scale, such as particularly spatial plans. This will allow to evaluate and compare the level of uptake of EbA measures in different contexts and different planning instruments, and to provide context-specific directions and recommendations for future improvements.

2.5 Conclusions and recommendations

As Munang et al. (2013a) put it, “integrating and mainstreaming EbA into decision making frameworks and planning processes are imperative”. Most plans are affected by a lack of specificity and details that may hamper the possibility for these measures to be actually implemented, as well as their overall effectiveness in reducing population vulnerability. Based on our findings, we can formulate the following recommendations to improve the consideration of EbA measures in climate adaptation plans:

1. The baseline information upon which EbA measures are pro-posed and designed needs to be enhanced. Methods to assess the existing stock of green/blue infrastructures, and their potential to provide climate adaptation services must be mainstreamed in planning practice. Particularly, assessments of the flow of ecosystem services at local scales are often missing, given that many climate change impact and vulnerability studies provide results at larger scales, limiting their usefulness for developing adaptation strategies at the local scale (Vignola et al., 2009). Abetter knowledge base, including information on spatial pat-tern of vulnerability, would allow to better target the design and implementation of EbA measures.
2. Co-benefits associated to EbA need to me made more explicit. One of the strongest motivation for promoting EbA approaches is that they bring environmental and

socio-economic benefits, beyond climate adaptation. A more formal analysis of the magnitude of the co-benefits need to be promoted in planning, in order to provide a stronger rationale for decisions involving EbA. Ideally, comparisons between EbA and alternative adaptation measures should be performed, as advocated by Joneset al. (2012). These analyses can take advantage of the methodologies and findings presented in the growing literature on the assessment and evaluation of ecosystem services (Kareiva et al.,2011), including its emerging streams focused on spatial planning (McKenzie et al., 2014) and impact assessment (Geneletti2013, 2011).

3. Interaction between climate adaptation plans and other planning instruments at the local level needs to be strengthen. Many EbA measures require space, hence compete with other land uses and needs in areas (urban settlements) where land resources are often scarce. A strong coordination with urban plans and other actions and policies is required to ensure that the proposed EbA measures are both feasible and desirable. The issue of integration between climate adaptation actions and other planning efforts has been raised by Preston et al. (2011), but has not received the required level of attention, even by the scientific literature.

Chapter 3

Estimating the cooling capacity of green infrastructures: A methodological proposal[**]

3.1 Introduction

Heatwaves have caused the most human fatalities among the natural disasters that occur in post-industrial societies: nearly 95% of recorded human deaths from natural hazards (Poumadere et al., 2005). During the summer of 2003, for example, the heatwave in Central and Western Europe was estimated to have caused up to 70 000 excess deaths over a four-month period (EEA, 2012). A study in Germany (Hubler et al., 2008) showed evidence of the fact that heat-related hospitalization costs increased six-fold in that period, not including the cost of ambulance treatment, and that heat also reduced the work performance, resulting in an estimated output loss of between 0.1% and 0.5% of GDP. Climate change is expected to increase heat island effect and the consequent rise of temperatures in cities during the summer in many regions of the world (Koomen and Diogo, 2015).

Ecosystem-based adaptation is defined as the use of biodiversity and ecosystem services to help people to adapt to the adverse effects of climate change (CBD, 2008). It represents an alternative approach to more traditional grey infrastructures and often proved to be cost-effective and able to provide a range of co-benefits, such as opportunities for recreation, biodiversity conservation and water regulation (Demuzere et al., 2014; Naumann et al., 2011; Vignola et al., 2009; Munang et al., 2013b, c). Among the most common ecosystem-based adaptation measures in cities are the creation and enhancement of Green Urban Infrastructures (GUI) (Munroe et al., 2012; Geneletti and Zardo, 2016). GUI contribute to reduce high temperatures in cities and the associated health risks, by virtue of their cooling capacity (Lafortezza et al., 2013; Escobedo et al., 2015). This ecosystem service, which

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belongs to the “micro and regional climate regulation” class of the CICES classification system (CICES v. 4.3, Potschin & Haines-Young, 2016) refers to the capacity of ecosystems to modify temperature, humidity and wind fields. Smith (2013) defines micro and regional climate regulation as the capacity of GUI to provide shelter from extreme weather, either cold or hot weather. In this paper, we focus on the cooling capacity of GUI, i.e. their capacity to mitigate high temperature in the summer (McPherson et al., 1997). GUI can lower temperatures in cities by almost 6°C (Souch and Souch 1993). In particular, the creation and restoration of GUI aimed at maximizing their cooling capacity can reduce energy costs in summer and limits the exposure of city dwellers to increased mortality induced by higher temperatures (Koomen and Diogo, 2015).

Urban plans are among the most important governance tools that can help to design and enhance GUI in cities (Kremer et al, 2013). However, a recent review showed that, even though there is in general good awareness of the potential role of GUI to address climate change challenges, their treatment in plans at the urban level often lacks sufficient baseline information (Geneletti and Zardo, 2016). The review concluded that a better knowledge base, including information on spatial pattern of ecosystem services flow at the local scale would allow to better target the design and implementation of GUI. Assessments of the flow of ecosystem services at local scales are often missing, given that many climate change impact and vulnerability studies provide results at larger scales, limiting their usefulness for developing adaptation strategies at the urban scale (Vignola et al., 2009). In addition, in the ecosystem services literature, the services provided by GUI are mostly assessed at large spatial scales (regional or national), which cannot capture the differences in different types and structures of GUI (Norton et al., 2015), since they mainly rely on coarser land use information (De Groot et al., 2010) . GUI may be very different in nature, including typologies such as parks, gardens, forests, green roofs and walls, and rivers (Naumann et al., 2010; Pauleit et al., 2011 and EEA, 2012). These typologies may differ in key components, such as soil cover, tree canopy cover, size and shape. Hence, they provide different ecosystem services, with different capacity (Bolund and Hunhammar, 1999; Bowler et al., 2010; De Groot et al, 2010; Chang et al., 2007). There is lack of information on GUI relevant for planning and decision-making at the urban scale (Larondelle and Haase, 2013), which requires more research in this area (Munang, 2013a; Braat and De Groot, 2012).

The aim of this study is to contribute to fill this gap by proposing an approach to estimate the cooling capacity provided by GUI that can be used to support urban planning. Evidence exists about the need for urban planners to effectively include the design and enhancement GUI into the planning practice as a measure to cool cities and combat urban heat islands. Yet, to our knowledge, no study specifically addressed this need by providing guidance for GUI planning and design. This paper aims at adds an important missing piece to the whole of the urban ecosystem services discussion.

Section 2 presents the rationale of the proposed approach and describes its four main steps. This is followed by our results, consisting in the assessment of the cooling capacity of different typologies of GUI (Section 3), and in an illustrative case-study application in the city of Amsterdam (Section 4). In Section 5, we discuss the approach and the case study findings, and then draw some conclusions on the approach and its potential contribution to urban planning in Section 6.

3.2 Methods

Ecosystem functions, defined as the ‘‘capacity of ecosystems to provide goods and services that satisfy human needs, directly and indirectly’’ (De Groot et al., 2010), are determined by the structure of an ecosystem, i.e., the architecture of its components (e.g., land cover, size, geometry, tree species) (De Groot et al. 2010). Following the cascade model (Haines-Young & Potschin, 2009), in our approach, we first identify the ecosystem functions of GUI involved in the cooling capacity (Section 2.1). Then, we identify the components associated to the functions, and we assess their contribution to cooling capacity (Section 2.2 and 2.3). Finally, we aggregate the results to determine the overall cooling capacity of GUI (Section 2.4). In Section 2.5, we assess the cooling capacity, and the associated change in temperature, for a set of GUI typologies, obtained by combining different components. The approach is based on an extensive analysis of the literature, covering mainly the fields of ES and urban forests, which was used to determine the cooling capacity of GUI in three different climatic regions: Atlantic region, Continental region and Mediterranean region. We classified climatic regions (adopting the classification scheme for climate regions by ETC/BD (2006) into three categories- namely, cool temperate moist (Atlantic), warm temperate moist (Continental), warm temperate dry (Mediterranean). The regions are defined by a set of rules based on: annual mean daily temperature, total annual precipitation, total annual potential evapotranspiration (PET), and elevation.

3.2.1 Identification of ecosystem functions and components

Shading, evapotranspiration (ETA) and wind are the three ecosystem functions that determine the cooling capacity of GUI (Oke, 1988; Taha et al., 1991; Akbari et al., 1992; Mc Phearson, 1997; Bolund and Hunhammar, 1999; Oke, 1988; Taha et l., 1991; Bolund and Hunhammar, 1999; Dobb et al., 2011; EEA, 2012; Smith, et al., 2013; Gomez and Barton, 2013; Mc Phearson et al., 2013; Larondelle and Haase, 2013). More specifically, vegetation regulates the urban microclimate in three ways: (i) by intercepting incoming solar radiation (shading); (ii) through the process of evapotranspiration and (iii) by altering air movement and heat exchange. Shading and evapotranspiration contribute most to the cooling effect (Skelhorn, Lindley & Levermore 2014). Additionally, considering the contribution of wind to cooling capacity assessments is particularly complex because it largely depends upon very local conditions that are not dependent on ecosystem functions and the components of GUI (e.g. presence of buildings, directions of streets, …) which require analysis at micro-scale of the shape of the open space and buildings (Bowler et al., 2010). For these reasons, this study did not address the wind factor in determining the cooling capacity of an area.

The components of GUI associated to shading and evapotranspiration were identified in: tree canopy coverage (Taha et al., 1991; Akbari et al., 1992; Bowler et al., 2010; Schwarz et al., 2011; Larondelle and Haase, 2013), soil cover (Akbari 1992; Souch and Souch 1993; Schwarz 2011; Larondelle and Haase 2013) and size (Chang 2007; Bowler 2010; Cao 2010). Our approach assesses the cooling capacity of different combination of these three components, for three different climatic regions, and assigns to the assessed GUI a cooling capacity score from 0 to 100 (where 100 indicates the best cooling capacity score) that can be associated to a potential decrease of the air temperature (°C) (Figure 3.1).

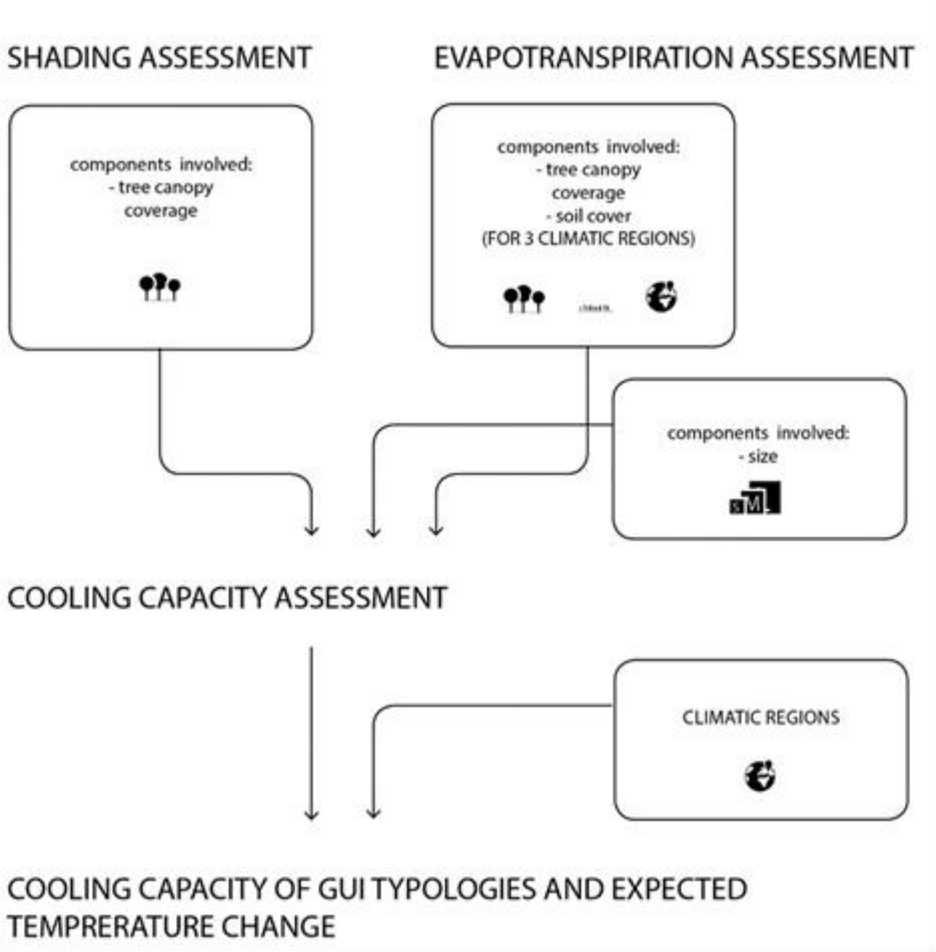


Figure 3.1 Flowchart of the proposed approach

3.2.2 Shading assessment

Several studies show evidence of cooler air temperature beneath individual or clusters of trees, highlighting the amount of shading as an important factor affecting temperatures (Taha et al., 1991; Akbari et al., 1992; Bowler et al., 2010; Schwarz et al., 2011; Larondelle and Haase, 2013). To represent this phenomenon, many indicators have been proposed. We adopted the “tree canopy coverage” which is expressed as the percentage of the ground area shaded by tree canopies relative to the total open area (Stronbach and Haase, 2012; Potcher 2006). There is a linear relationship between the presence of tree covers and shading (Potcher et al., 2006). Hence, our assessment was based on a linear scale applied by Visual estimation (e.g., Dethier and Duggins, 1984): the technique views the system as essentially 2-D from the sky, with a maximum of 100% of area covered by trees. Hence, we assigned a shading score equal to of “x” to GUI with a x% tree canopy coverage. In our analysis we only consider the contribution given by trees with canopy equal or higher than two meters, assuming that lower cover does not provide shade that is useful for human beneficiaries. Nevertheless, such vegetation has a significant contribution in terms of evapotranspiration, which we discuss next.

3.2.3 Evapotranspiration assessment

The literature identifies as components that affect evapotranspiration: tree canopy coverage, soil cover and tree species. Tree canopy cover of a GUI is an important component to consider because trees do evapotranspirate, so according to their capacity they contribute to total ETA (Taha 1988; Taha 1991; Akbari 1992; Bowler 2010; Schwarz 2011; Larondelle and Haase 2013). Similarly, soil cover shall be taken into account because different types of soil evapotranspirate differently according to their capacity (Kc) (Akbari 1992; Souch and Souch 1993; Schwarz 2011; Larondelle and Haase 2013). To conclude, tree species is mentioned by the literature because different types of trees have different evapotranspiration capacity (FAO 1998; Larondelle and Haase 2013).

Additionally, given a specific combination of these three components, their evapotranspiration differs according to the climatic region (Taha 1991; Akbari 1992; Mc Phearson 1997; Bowler 2010). In warm and dry areas evapotranpiration is more effective (higher values) than in humid or cool climates (Taha, 1991; Akbari, 1992; Mc Phearson, 1997; Bowler, 2010). In this study we disregarded tree species because this information that is hardly available at city scale. Additionally, differences across species in terms of evapotranspiration are found to be negligible for the scale of our assessment (Souch and Souch, 1993).

Evapotranspiration values were derived using the equation (FAO, 1998):

$$ET_c = K_c \, ET_0 \qquad (1)$$

where ETc is the tree or soil cover evapotranspiration (ETA) under conditions of unlimited presence of water in the ground (irrigated), Kc is the tree or soil cover coefficient and ET0 is the reference evapotranspiration.

The equation shows that evapotranspiration depends not only on specific characteristics of the surface (Kc coefficient), be it soil cover or tree, but also relies on climate: ET0 represents the climatic region implications.

To estimate the evapotranspiration potential of a GUI we need to consider its soil cover and tree canopy coverage to obtain the soil and trees Kc coefficient. ETA can be estimated by multiplying its specific Kc coefficient for the climate-specific value ET0 (Larondelle and Haase, 2013; Schwarz et al., 2011; Kremer et al., 2013) by considering the ET0 corresponding to the specific climatic region considered for the analysis. The ETA of a given GUI is obtained by summing the ETA related to trees in that climatic region multiplied by the tree canopy coverage (e.g. 0.3 if the tree canopy coverage category is 30%) and the ETA related to the soil cover in that climatic region multiplied by the surface area not covered by trees (e.g. 0.7, if in case of 30% tree canopy coverage). The ETA values (expressed in mm d^-1) obtained through the application of equation (1) were converted into a ETA score in the 0-100 range.

3.2.4 Cooling capacity assessment

The relative contribution of shading and evapotranspiration to the overall cooling capacity is determined by the third component, i.e. the size of the GUI (Chang et al., 2007; Bowler et al., 2010; Cao et al., 2010). Evapotranspiration and shading jointly reduce the air temperature, but the impact of evapotranspiration becomes predominant as the area gets larger (Akbari et al., 1992). Unfortunately, only limited information is available in the literature on how to combine the contribution of evapotranspiration and shading, and the relationship between size and cooling capacity is non-linear (Chang et al., 2007). According to Chang et al. (2007), green areas larger than 2-3 hectares are much cooler than their surroundings (Chang et al. 2007). Additionally, parks between 3 and 12 hectares are cooler than most surrounding measurements; whereas parks smaller than 2 hectares have a limited effect. Many studies identify the threshold between "small" parks and "large" parks around a value of 2 hectares (e.g. Shashuabar and Hoffman, 2000; Chang et al., 2007; Cao et al, 2010; Bowler et al., 2010). Cao et al. (2010) showed that green areas smaller than two hectares are on average 1°C cooler than surrounding areas while above the threshold the temperature decreases rapidly (from 2°C to 4°C) drawing a curve which flattens around the eight hectares. Akbari et al. (1992) analyses the effects of shading and ETA on surroundings of trees (measurements were taken at 12 m and five m from trees). They concluded that the cooling capacity depends mainly on ETA for large areas, reaching a distance as far as five times the tree. Akbari et al.

(1992) found that shading contributes up to 95% when directly under the canopy, but its contribution in the decrease of temperature and consequently of energy consumption for air conditioning for the 40% for large areas (larger than two hectares). Chang et al. (2007) found that size contributes to 60% of the cooling capacity, and directly affects the contribution of ETA. In areas smaller than two hectares, empirical studies determined the contribution of shading to be around 80% of the total cooling capacity, with the remaining 20% determined by ETA (Shashuabar and Hoffman, 2000).

These findings suggested to assess the overall cooling capacity of GUI through a weighted summation of their ETA and shading scores, using different weights according to size. Particularly, in areas smaller than two hectares ETA was assigned a weight of 0.2 and shading of 0.8. In areas larger than two hectares the weights were changed to 0.6 and 0.4, for ETA and shading respectively. Results are standardized in a scale from 0 to 100. However, Chang (2007) shows that areas with less than 50% tree canopy coverage risk to become warm islands instead of cool islands during some part of the day in very hot summer. To consider this remark, we calculated the cooling capacity of all areas as described above, but we highlight with a "*" cooling capacity scores for all areas below 50% tree canopy coverage to underline that even if they may present generally good cooling capacity scores, in some circumstances they can also work the other way round.

3.2.5 Cooling capacity of GUI typologies and expected temperature change

GUI typologies were identified by combining the components previously described. To this purpose, tree canopy coverage was classified five classes: 0 - 20%, 21-40%, 41 - 60%, 61 - 80% and 81 - 100%. Soil cover was classified into the following classes (based on the HERCULES soil-cover taxonomy, Cadenasso et al. (2007): sealed (all impervious surfaces), bare soil, heterogeneous cover (mixed cover of bare-soil and shrubs, typical of vegetable gardens or inner courts or some vacant lots), grass (fine vegetation) and water. Size was classified into two classes (see rationale in Section 2.3): below and above two hectares. By combining these classes, we obtained 50 typologies of GUI, which were considered in the three climatic regions.

To assess the cooling capacity of each GUI typology in each climatic region, we collected on ET0 and Kc. ET0 data for the three climatic region were obtained from the CGMS database of the Mars Crop Yield Forecasting System (https://ec.europa.eu/jrc/en/research-topic/crop-yield-forecasting). For E0, we considered the E0 values for six different cities located in the three different climate regions (Amsterdam and Rotterdam for the Atlantic, Milan and Venice for the Continental, Madrid and Barcelona for the Mediterranean. From the same database, we obtained Kc values for the five different soil cover categories. We found an average Kc for trees by referring to FAO (1998), taking into consideration Citrus and Conifers –which represent respectively the highest and lowest values in the table- values during the summertime. For Kc, we consider conditions with unlimited water in the ground assuming urban ecosystems can be easily irrigated.

As a last step, the cooling capacity scores were associated to expected changes in temperature through a literature review. The conversion of cooling capacity scores (expressed in scores from 0 to 100) into changes in air temperature depends heavily on the climatic region: GUI can lower daily maximum near-surface temperature more in hot and dry conditions than in cooler and damper conditions (Taha et al., 1991). Table 3.1presents the literature that was used to estimate the changes in temperature. These studies refer to air temperature decrease in urban contexts, due to the presence of GUI. The studies were clustered according to their climatic region (applying the Koppen classification, Peel et al. 2007), and used to identify a minimum and a maximum values of temperature variation for cities belonging to the three three climatic regions recorded by the articles.

We matched the data that emerged from the literature review (see Table 3.1) with the 0-100 cooling capacity scores. More specifically, first we assigned the maximum cooling value expressed in °C to the highest cooling capacity scores (100) for each of the three climatic regions (e.g. GUI with a cooling capacity of 100 might lower the temperature of 3.5°C in the Atlantic region, 4.8°C in the Continental region and 6°C in the Mediterranean region. Then, we divided the maximum cooling value for each region in five, assuming the temperature decrease provided would decrease linearly with the decrease of the cooling capacity. For example, in the Atlantic region, to any 20 points of cooling capacity corresponds a decrease of °C of 0.7: GUI with cooling capacity from 0 to 20 can lower the temperature up to 0.7°C, from 21 to 40 up to 1.4°C, from 41 to 60 up to 2.1°C, from 61 to 80 up to 2.8°C, from 81 to 100 up to 3.5°C.

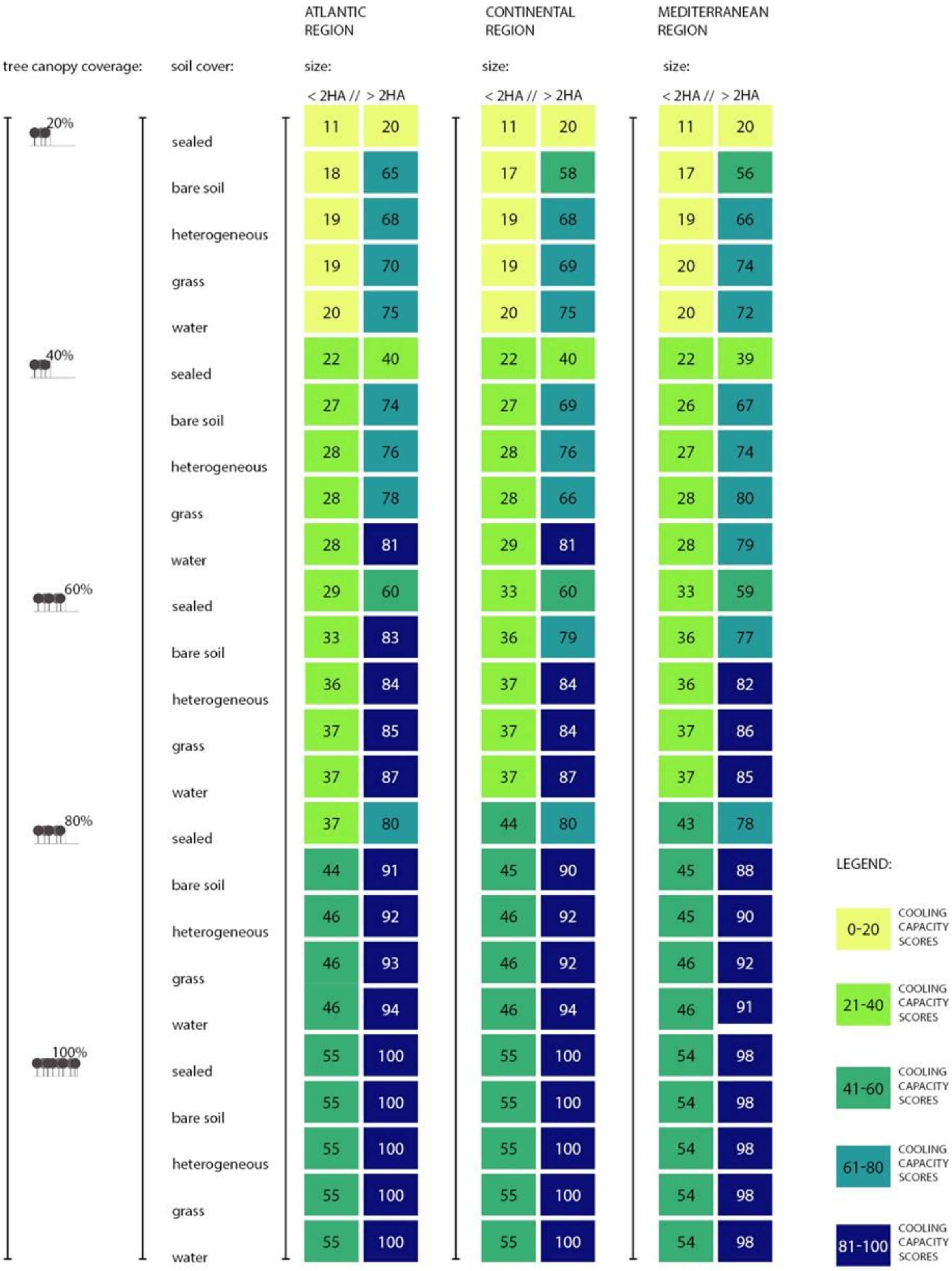
Table 3.1 Literature review for cooling capacity (delta T°C)

Climatic area	Min cooling (°C)	Max cooling (°C)	Reference
Atlantic (Koppen:Cfb)	1.0	3.5	Larondelle and Haase, 2012; Schwarz et al., 2011; Watkins, 2002; Authority, G. L. 2006
Continental (Koppen: Cfa)	1.0	4.8	Chang et al., 2007; Potcher et al., 2006
Mediterranean (Koppen: Csa)	1.7	6.0	Taha et al., 1991; Souch and Souch, 1993; Shashua-Bar and Hoffman, 2000; Potcher et al., 2006

3.3 Results

Figure 3.2 summarizes the cooling capacity of the 50 GUI typologies for the three climatic regions. From our analysis, 26% of the GUI typologies show the highest scores (from 81 to 100), 17% of GUI from 61 to 80, 23% from 41 to 60, 23% from 21 to 40, 12% from 0 to 20. These findings reveal a ranking among the four components in terms of their influence on the overall cooling capacity of a GUI (see Figure 3.2). Thus, all GUI showing scores above 60 present a size above the two hectares and only 3% of the GUI above the two hectares show scores from 60 below, exhibiting that size is the most influent component among the three. A group of six GUI represents the exception: they are characterized by the best size category (above two hectares) but show the worst conditions in terms of soil cover and tree canopy coverage. Furthermore, no GUI with size smaller than two hectares show scores above 60. This can be seen reading the right colon of GUI inside each of the three colon corresponding to a climatic region.

Scores between 41 and 60 comprise mainly areas smaller than two hectares (91%). This includes all the GUI with 100% of tree canopy coverage, and most of GUI with 80% of tree canopy coverage. The GUI with scores between 21 and 40 are smaller than two hectares and have tree canopy coverage between 20 and 60%. We can observe that, the second most influential component, after the size, is the tree canopy coverage. Soil cover follows tree canopy coverage (in the ranking by importance). Thus GUI with low cooling capacity (scores below 40) represent GUI with size smaller than two hectares, tree canopy coverage below the 60% and slightly distinguish themselves according to the soil cover.



tree canopy coverage:	soil cover:	ATLANTIC REGION size: < 2HA	ATLANTIC REGION size: > 2HA	CONTINENTAL REGION size: < 2HA	CONTINENTAL REGION size: > 2HA	MEDITERRANEAN REGION size: < 2HA	MEDITERRANEAN REGION size: > 2HA
20%	sealed	11	20	11	20	11	20
	bare soil	18	65	17	58	17	56
	heterogeneous	19	68	19	68	19	66
	grass	19	70	19	69	20	74
	water	20	75	20	75	20	72
40%	sealed	22	40	22	40	22	39
	bare soil	27	74	27	69	26	67
	heterogeneous	28	76	28	76	27	74
	grass	28	78	28	66	28	80
	water	28	81	29	81	28	79
60%	sealed	29	60	33	60	33	59
	bare soil	33	83	36	79	36	77
	heterogeneous	36	84	37	84	36	82
	grass	37	85	37	84	37	86
	water	37	87	37	87	37	85
80%	sealed	37	80	44	80	43	78
	bare soil	44	91	45	90	45	88
	heterogeneous	46	92	46	92	45	90
	grass	46	93	46	92	46	92
	water	46	94	46	94	46	91
100%	sealed	55	100	55	100	54	98
	bare soil	55	100	55	100	54	98
	heterogeneous	55	100	55	100	54	98
	grass	55	100	55	100	54	98
	water	55	100	55	100	54	98

LEGEND:

0-20 COOLING CAPACITY SCORES

21-40 COOLING CAPACITY SCORES

41-60 COOLING CAPACITY SCORES

61-80 COOLING CAPACITY SCORES

81-100 COOLING CAPACITY SCORES

Figure 3.2 Overall cooling capacity for the 50 GUI considered for three different climatic regions

In terms of expected temperature changes, the Mediterranean region is where larger changes occur, followed by the Continental area and the Atlantic region (Figure. 3). For example a GUI with a score of 100 for the cooling capacity in the Atlantic region can provide a temperature decrease up to 3.5°C. The same GUI in the Mediterranean region can provide a temperature decrease of up to 6 °C. Additionally, each score implies a different temperature decrease, according to the climatic region. Consequently investing on a GUI to improve its cooling capacity from 60 to 80 a region, implies a different jump in terms of temperature decrease. For example between two GUI with a cooling capacity of 60 and 80 respectively in the Atlantic region implies a shift around 0.7°C, while in the Mediterranean around 1.2°C. This means that if we would aim for a decrease of one Celsius degree, in the Atlantic we would need to upgrade the GUI score of almost 40 points (out of 100), while in the Mediterranean region it would be sufficient to upgrade the Gus score of only 20 points (out of 100). This can be observed in Figure 3, where the grey rectangle represents a shift of one Celsius degree.

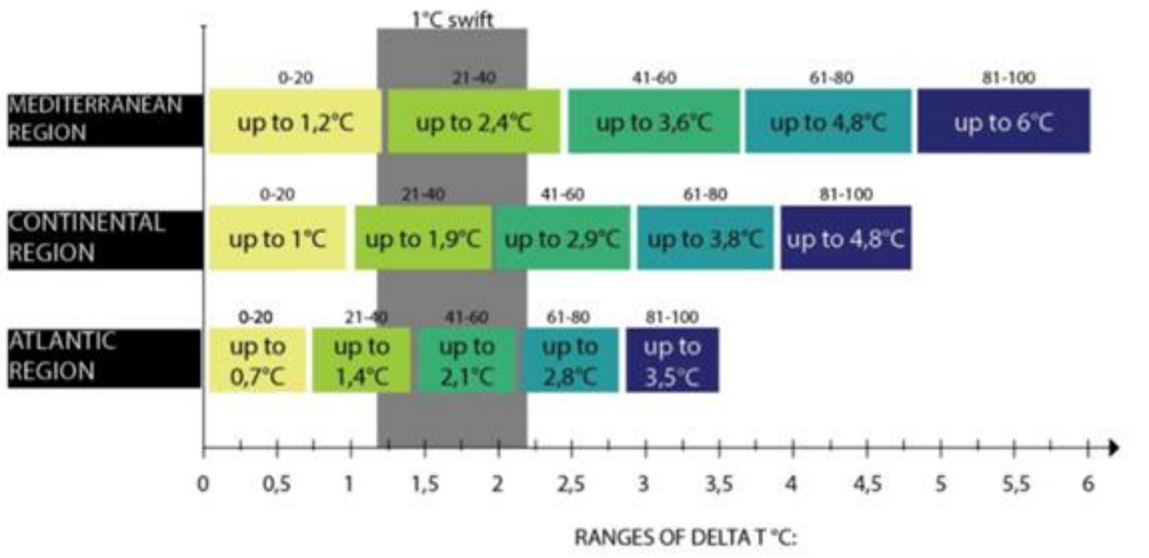


Figure 3.3 Figure 3 shows the delta Temperature variation (in Celsius degrees) for the same classes in the three different climatic regions.

3.4 Application to the city of Amsterdam

The approach was empirically applied to a 10X10 km portion of the city of Amsterdam, by analyzing existing GUI, and assessing their cooling capacity. Amsterdam belongs to the cold temperate moist zone, which correspond to the Atlantic climatic region. Tree canopy coverage was mapped using spatial information data from the "Actuel Hoogtebestand Netherland" (height map for the Netherlands, http://www.ahn.nl/index.html) and applying the NDVI index (Normalized Difference Vegetation Index) to remove non-vegetated objects from the digital terrain model such as buildings or trucks. Soil cover and GUI size were mapped using the topographic map of the Netherlands (LGN map for the Netherlands from the Alterra Research Centre, 2014). From the land use map, streets were identified as large surfaces (far beyond two hectares), because the whole network was drawn as a unique polygon. Since the network shape relies to a final large area in terms of surface but its biophysical behavior does not relate to the real large areas one (because it is not enough compact), we applied a shape index formula (LSI: perimeter/(2*square root of (Pi*Area)) utilizing “6” as minimum threshold to avoid networks . All GIS operations were conducted using QUICKScan (Verweij et al., 2012). 74653 GUI, covering 8477 hectares, were mapped. The GUI tree canopy coverage, soil cover and size maps are shown in Figures 3.4., 3.5 and 3.6 respectively.

Most GUI consisting of water or have a tree canopy coverage below 20%. The remaining GUI represent less than 10% of the overall GUI area and are characterized by a heterogeneous soil cover and tree canopy coverage below 20% (17% of overall GUI area), sealed patches with tree canopy coverage below the 20% (11%), sealed patches with tree canopy coverage between 20 and 40% (10%) and grass soil cover with tree canopy coverage below 20% (10%).

Figure 3.7 presents the results of the cooling capacity assessment. In particular, Figure 3.7 presents the overall cooling capacity of GUI in the city, with scores from 0 to 100. Most GUI have a low cooling capacity (the 34% of total GUI present cooling capacity scores below 25). The 13% of GUI present scores from 25 to 30, the 22% of GUI present scores from 30 to 60 and only the 1%of GUI present scores above 60. Linking the cooling capacity scores with the potential decrease of temperature analyzed in the previous paragraph, we can assume that the 22% of GUI between 60 and 30 may lower the temperature during the summer days up to 2.1°C.

The results can be used in urban planning to identify possible actions to enhance the cooling capacity of least performing GUI. For example, Figure 3.8 shows a possible set of interventions to upgrade a GUI with a current cooling capacity score of 11, characterized by size below two hectares, 20% of tree canopy coverage and sealed soil. The best results are provided by a combination of actions targeted at increasing the size and the tree canopy coverage, and improving soil cover).

Figure 3.4 Soil cover map

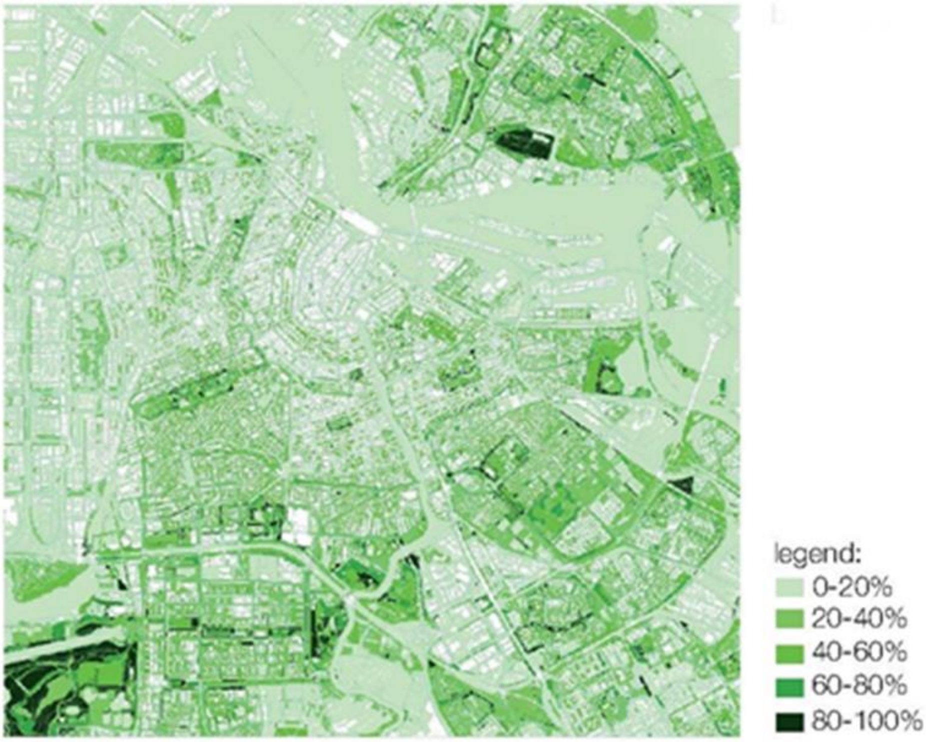


Figure 3.5 Tree canopy coverage map

Figure 3.6 Size map

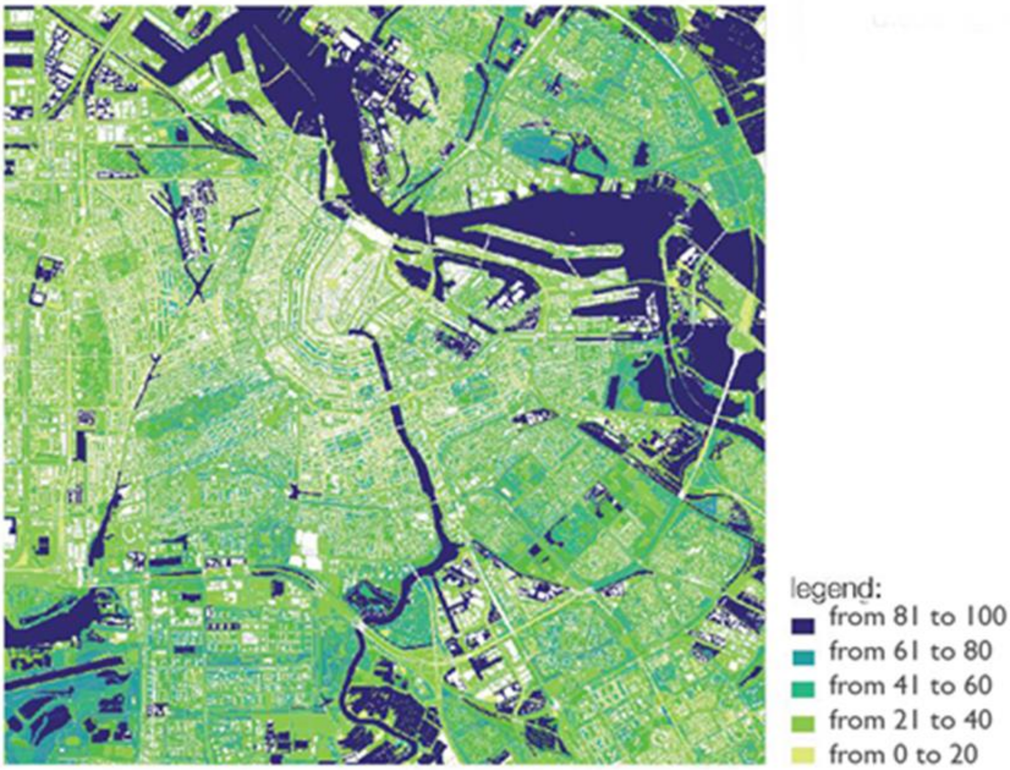
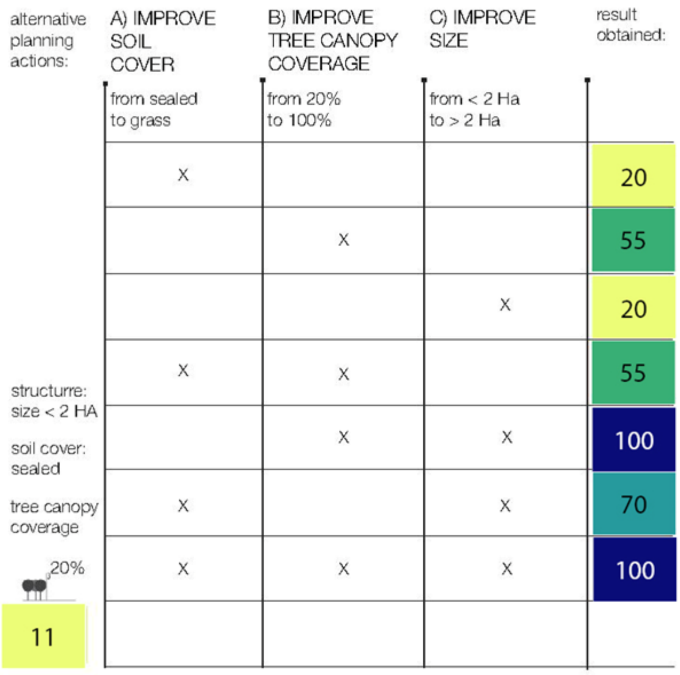


Figure 3.7 Overall cooling capacity map



alternative planning actions:	A) IMPROVE SOIL COVER from sealed to grass	B) IMPROVE TREE CANOPY COVERAGE from 20% to 100%	C) IMPROVE SIZE from < 2 Ha to > 2 Ha	result obtained:
	X			20
		X		55
			X	20
	X	X		55
structurre: size < 2 HA		X	X	100
soil cover: sealed	X		X	70
tree canopy coverage 20%	X	X	X	100
11				

Figure 3.8 Alternative actions to upgrade an hypothetical GUI with a cooling capacity scores below 20 (characterized by a size < two hectares, soil cover sealed and tree canopy coverage of 20%) and the cooling capacity reached according to the action or combination of actions applied (i.e. by increasing the soil cover and the tree canopy coverage the GUI is upgraded).

3.5 Discussions

GUI represents a potential for cities to adapt to multiple challenges. In particular, the potential that GUI represent in terms of ES provisioning, determines the relevance and need to take into account the design of GUI and their ES provisioning in decision-making and planning processes (Munang et al., 2013).Lack of data may hamper the application of ecosystem-based actions such as creation or restoration of GUI. On the other hand, too complex and specific tools also present a possible barrier for improving the design of GUI in urban planning practice.

In this paper, we focused on a single ecosystem service, cooling, out of the bundle of services provided by GUI. Our approach links the components that constitute of the structure of a GUI to its capacity to provide cooling, distinguishing among typologies of GUI, which larger scale assessments are not able to do.. Thus, results show the differences in the expected cooling capacity from one GUI typology to another.

The results show that the three GUI components do not influence equally the cooling capacity. Additionally, the performance of different typologies of GUI relatively to one another is constant across climate regions (i.e. a GUI x is better than GUI y in all climatic regions). The impact of the climatic region becomes important in decrease of the air temperature (°C) provided by a GUI, as Section 3.2 shows. Generally, the most important component is size, followed by tree canopy coverage and lastly soil cover. Additionally, highlighted that among categories of one component (for example “soil cover”) some thresholds emerge to be more significant than others (e.g. the major difference is between “sealed” and the other four categories, namely bare soil, heterogeneous, grass and water).

In Section 3.2, we showed that a specific GUI, with a specific class of cooling capacity, implies a different decrease of the air temperature depending on the climatic region. More specifically, in the Mediterranean region the same GUI can lower the temperature more effectively than in Atlantic or Continental regions. Apart from this, results from Section 3.2 also showed that in Mediterranean regions greater cooling can be reached. Concluding, to obtain a decrease the air temperature of 1°C, Atlantic regions need a switch of some classes of cooling capacity while in the Mediterranean a switch from one cooling capacity class to another is sufficient: from a practical point of view this has different investment implications.

The Amsterdam case study showed that our approach requires only a limited set of input-data, generally easy to obtain, to provide an overall cooling capacity assessment of GUI. From the case study, several practical insights emerge related to the different effects of the components in different cases. For example for small areas shading is much more determining than for large areas, making the increase of tree canopy coverage particularly interesting for small spaces, especially compared to soil cover interventions. In general, soil cover investments are more indicated for large areas, while for small areas promising cooling capacity can be obtained just by increasing the tree canopy cover, with exceptions in the Mediterranean region where again trees are more preferable than soil cover interventions, but with less difference between the two. On the contrary, for large areas soil cover changes can provide much more interesting results in all three climatic regions, especially in the Mediterranean. However, a good balance in terms of tree-canopy coverage, soil cover type and size, as mentioned in the previous paragraph, is the strategy providing the best cooling capacity.

The approach, as it stands now, has three main limitations discussed hereafter.

i)The computations of shading, evapotranspiration and overall cooling capacity are based on a review of the available literature and on expert opinion. However, the need for a cross-disciplinary approach to enhance an ecosystem-service oriented planning as propagated by Norton et al. (2015) may imply methodological difficulties such as comparing similar but different variables from diverse studies, selecting values and data from similar contexts (climatic regions), and accepting the lack of true replications of some empirical studies (see also Bowler 2010).

ii) Variables such as wind flowing, city morphology, , tree species were not considered due to the choice for simplicity and synthesis, looking for a fair trade-off between accuracy of the assessment and a complexity in computations and data. Thus, cooling capacity of a green area in a city may be due to infinite combinations of different urban geometries and climate variables (Oke, 1988), but planning and design can make a difference in choosing between alternatives. Therefore we have restricted the analysis to the most influencing factors, but flexible enough to provide site-specific solutions. Additionally, among the infinite variables contributing to cooling capacity, wind was not included in our approach also because we found conflict in the literature about the positive or negative role of wind, as mentioned in section 2. Similarly, for tree species, the literature provides evidence about the fact that different tree species differently contribute to cooling due to different evapotranspiration functioning (captured in equation 1 in the Kc value). However, the consideration of tree species in the approach represents a type of data challenging to obtain at city level and on the other hand, the difference between species in terms of evapotranspiration was found to be negligible for the scale of our assessment (Souch and Souch, 1993), as mentioned in Section 2. Additionally, we computed the ETc difference of a same area between considering or avoiding “tree species” as component for evapotranspiration assessment. We computed the potential effect of this component taking into account different species and their respective Kc values, including the average value of 0.8 for trees, the lowest value of 0.4 for fruit trees at the beginning of the season and the highest values of around 1 for conifers (Fao, 1998). Multiplying these Kc values by the E0 related to the different climatic areas, we found the variation to be negligible, which is consistent with the conclusions of a study of Souch and Souch (1993). For the difference to be appreciated the whole area had to be covered by specific species of tree, in which case the shading effect would have outweighed the evapotranspiration effect anyway. Thus, the choice to keep the average value of Kc 0.8 without adding further complexity at this level.

iii) It considers only the cooling capacity within the GUI, without addressing the effects outside its boundaries. Clearly, knowing the spatial extent of the cooling capacity beyond GUI boundaries would be interesting for urban planning, and for an analysis of the expected beneficiaries of different GUI interventions.

3.6 Conclusions

Scientific knowledge from different fields, such as ecology, planning, urban forestry and climate-related studies, can improve GUI assessment tools, but an effort in terms of converting it into guidance that can improve urban planning processes is still needed (Norton et al., 2015) Our approach is the result of an effort to combine knowledge and data from different disciplines to contribute to this purpose. The approach presented in this paper and the information it provides are designed to fit the urban scale and to work with input-data sets that are sufficient to differentiate among the cooling capacity provided by different types of GUI, but still easily available during urban planning processes.

Further research will be needed to link this approach and the insights it provides for assessing cooling capacity with an explicit assessment of beneficiaries. Comprehensive and accurate analyses of beneficiaries are needed as a tool to design and assess ecosystem-based measures. Moreover, identification, quantification and mapping of beneficiaries are essential steps to highlight and face equity issues in the provision of ES, spatial mismatches between ES supply and demand, trade-offs between different categories of beneficiaries.

Chapter 4

Testing the application of Ecosystem Service assessments in two case studies

4.1 Introduction

The assessment of ecosystem services aims at the quantification of benefits derived from ecosystems to inform planners and politicians, who develop plans and strategies for the protection of the environment and the provision of socially requested services (BMU, 2007; Farley and Costanza, 2010). Many issues remain to be resolved to fully integrate the concept of ES into everyday planning, management and decision-making (De Groot et al., 2010). One of the major barrier to the application of ES is the gap between a dramatically growing literature (see Haase et al. 2014; Luederitz et al. 2015 on urban ecosystem services) and the planning and management practice (Geneletti and Zardo, 2016). Hence, practitioners face many challenges, from the conflict between lack of data availability and the high number of data required as input for ES models, to the need for synthetic results that contrasts the high complexity of adaptive systems such as cities and social-ecological systems in general.

ES assessments and the variety of methods and tools to support urban planning in the consideration of urban ecosystems can support planners in creating and restore ecosystems that effectively enhance human well-being and ameliorate quality of life in cities. I the last years, research from the ES field is putting evident effort to deliver proper methods and tools with the specific purpose of supporting urban planners. However, since purposes and challenges that urban planning faces are many, also the information required cannot be delivered by one single tool or methodology (UNU, 2003). Depending on the scale and purpose of the planning question, different types of ES assessment are required.

The availability of ES assessment tools for urban applications is still scarce, especially compared to larger scales, as shown in Chapter 2 and Chapter 3. A coherent and integrated approach to come to practical application of the concept of ecosystem and landscape functions in planning, management and decision-making is still lacking (ICSU et al., 2008). Additionally, methodologies and tools for the assessment of the ecosystem services provided by green urban infrastructures (GUI) tend to be too data demanding for being routinely adopted in urban planning processes. To transfer the concept of ecosystem services to urban planning, integrated and easily applicable assessment approaches are needed (Burkhard et al., 2010; de Groot, 2006; Frank et al., 2010b; Lautenbach et al., 2010; Rannow et al., 2010). Moreover, information on successful and cost-effective Ecosystem-based measures such as the creation of GUI is lacking and needed especially at the city scale (Norton, 2015; Larondelle and Haase, 2013). ES assessments at the city scale should be specific enough to distinguish among different types of GUI as different ES providing units.Indicators that consider urban ecosystems as a homogenous category cannot guide planning actions in the choice and implementation of different GUI.

To conclude, to mainstream the use of ES assessments and their results to answer to planning questions, there is need to provide evidence about the relevance/contribution.

Goal of this chapter is applying ES assessments to two different contexts test and discuss the applicability of methods to support the planning practice. Focusing specifically on the application of scientific findings in everyday planning practices, this chapter provides some insights on the applicability of ES assessments to support urban planning decisions, particularly by:

-applying the methodology to assess the cooling capacity of GUI (Chapter 3) to evaluate urban development opportunities regulated by the existing urban plan in the city of Trento (Italy);

-applying a multiple-ES assessment to identify priority neighborhoods for interventions based on the mismatch between ES supply and demand in Addis Abeba (Ethiopia);

-drawing some conclusions about the capability of ES assessments to inform real-world planning processes.

4.2 Trento case study[***]

The Trento case study is based on: Geneletti D., Zardo L., Cortinovis C. (2016), Promoting nature-based solutions for climate adaptation in cities through impact assessment, in D. Geneletti (Ed.), Handbook on Biodiversity and Ecosystem Services in Impact Assessment, Elgar Publishing.

The city of Trento is located in an alpine region in Northeastern Italy. Trento is a city of

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[***] The Trento case study is based on: Geneletti D., Zardo L., Cortinovis C. (2016), Promoting nature-based solutions for climate adaptation in cities through impact assessment, in D. Geneletti (Ed.), Handbook on Biodiversity and Ecosystem Services in Impact Assessment, Elgar Publishing.

around 100 000 people that sprawls about 10 km across the Adige valley floor (Figure 4.1). This section shows how the results of the cooling capacity assessment performed on the GUI of Trento can be applied to support urban planning and associated impact assessment processes. More in detail, the application refers to the re-development of brownfields as one of the strategies envisioned by the current urban plan of the city. Different greening interventions are simulated for each brownfield, and the associated cooling capacity is assessed to identify the sites, and the types of intervention, that provide the highest benefits to citizens, considering also their differentiated vulnerability to heat waves.

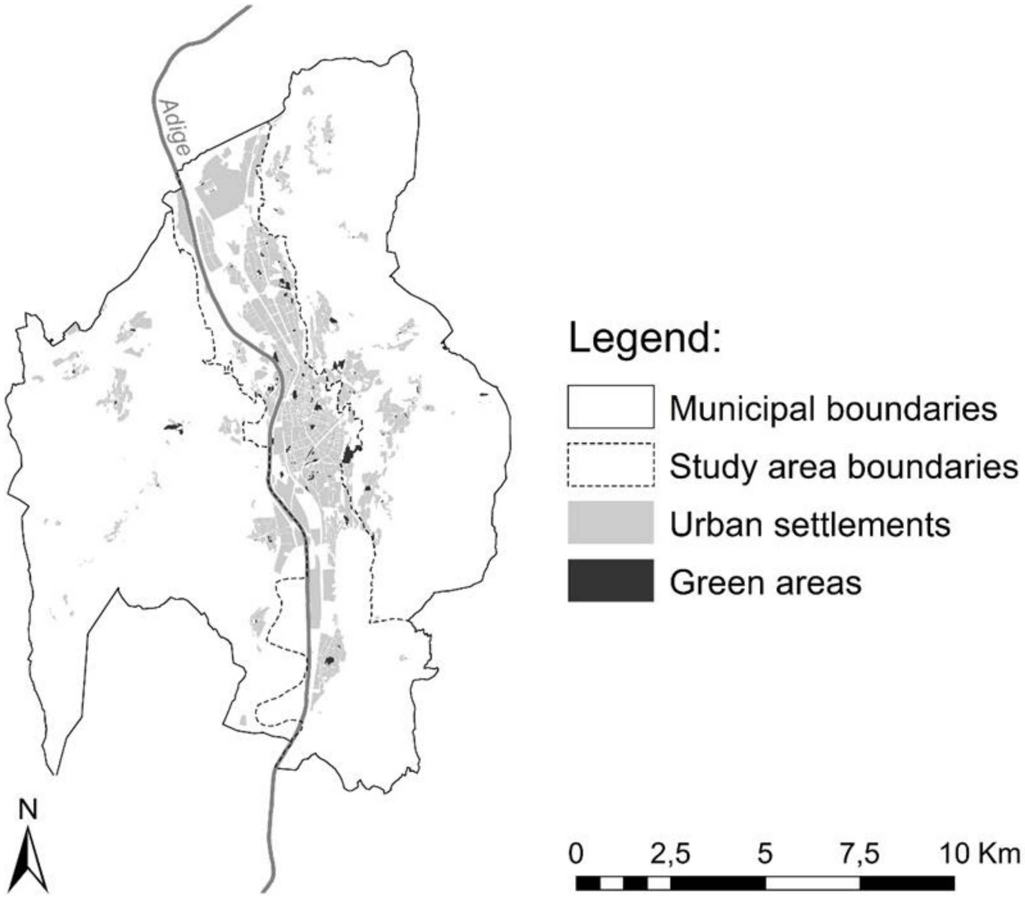

Figure 4.1 City of Trento

4.2.1 Methods

To assess the cooling capacity provided by all GUI in Trento, we adopted the methodology presented in chapter 3. We simulated for each brownfield two different greening interventions (scenario A and scenario B) resulting in different cooling performances, and we measured the number of people that would benefit from the transformation based on the comparison with the existing situation (baseline). This enables us to understand how and where it is more cost-effective to intervene through ecosystem-based measures and to understand which area can be more effectively transformed through greening actions, which level of performance is required to increase the well-being of the surrounding inhabitants, and in which area the same investment is expected to obtain the biggest gain.

The GUI of Trento were mapped and classified according to the key components considered in the methodology, namely tree canopy coverage, soil cover and size. This information was then aggregated using the cooling capacity values for the Mediterranean climatic area (see details in chapter 3), obtaining the map presented in Figure 4.2 (left). The spatial decay functions mentioned above allowed mapping the flow of the ES outside the boundaries of GUI (Figure 4.2, right).

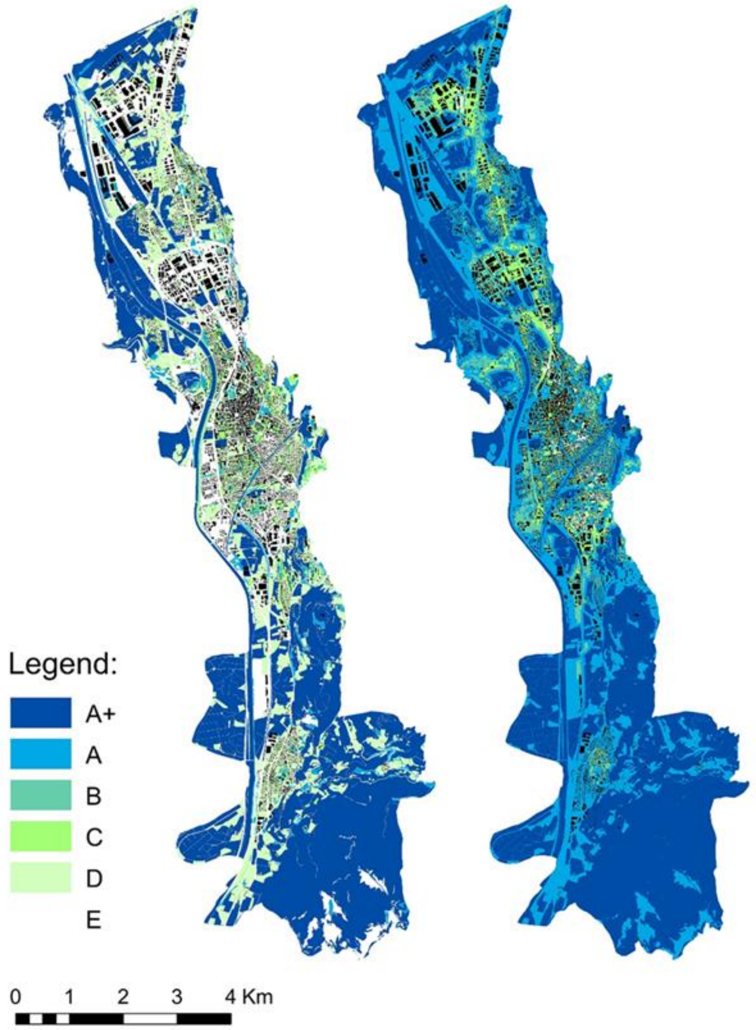

Figure 4.2 Assessment of the cooling capacity of the GUI of Trento. Left. Cooling classes within GUI. Right: Cooling classes also outside GUI.

For each area, we simulated two transformation scenarios applying different greening interventions, and modeled the expected cooling capacity. Scenario A refers to the ‘best cooling performance’ that can be reached depending on the size of the brownfield (cooling capacity score above 80 in Figure 3.2). Scenario B simulates a ‘medium-level cooling performance (cooling capacity score between 31 and 50). The same class of cooling capacity can be obtained through different combinations of land cover and tree coverage. Scenario A, for example, can be obtained through a homogeneous grassy area with tree coverage higher than 80 percent (e.g., an urban forest or an intensely planted urban park). Scenario B corresponds to a high tree coverage over a sealed surface (> 40 percent for the bigger areas and > 60 percent for the smaller ones), such as an intensely-planted parking area. We considered all the transformations independently and computed for each scenario the map of the cooling capacity inside the maximum area of influence of each brownfield. Through an overlay between this map and the census data, we determined the number of people living within each cooling class under the different scenarios.. To assess the benefits provided by each scenario, we performed a spatial comparison with the baseline condition. We computed a map of the expected differences in class: positive values stand for changes from lower to upper classes, negative values for changes from upper to lower classes. The overlay between this map and the census data allowed us to estimate the number of people affected by positive or negative changes.

We considered both total population and specific vulnerable groups. To define vulnerable groups, we referred to the analyses by Kabisch and Haase (2014) and Kazmierczak (2012) and identified elderly people (above 65 years old), children (under 5 years old), and foreigners as the most sensitive and less adaptive to heat stresses. Census data provided by the municipality about total number of residents, age group distribution, and presence of foreigners for each census block were collected and linked to the spatial map. To be as accurate as possible in the spatial definition of the population, we identified the residential buildings inside each census block and distributed the residents only in the surface covered by their footprint.

The analysis was performed on 13 brownfields identified by the Urban Plan as areas for future re-development. Most of them are former industrial sites or partially abandoned residential areas (see Figure 4.3, right). Their dimension ranges from 0.5 to 9.9 ha. Among them, seven are larger than 2 ha, thus the maximum distance that can be reached by their cooling effect on the surroundings is around 250 m. For the smaller ones, the maximum buffer of effect is 100 m from the boundary.

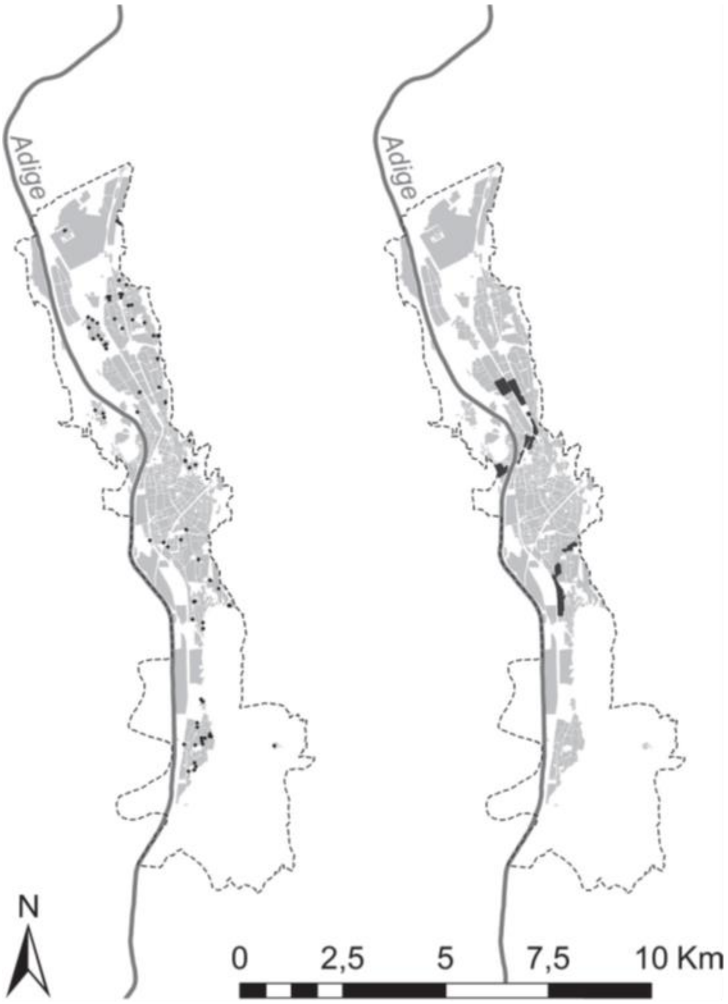

Figure 4.3 The sites classified by the Trento Urban Plan as vacant lots for residential development (left) and as brownfields for future re-development (right) that have been considered in this study

4.2.2 Results

Figure 4.4 and Tables 4.1, 4.2 and 4.3 present the results obtained for one of the re-development sites, while Figure 4.5 summarizes and compares the performance of all brownfields under the two different greening scenarios with respect to the existing condition.

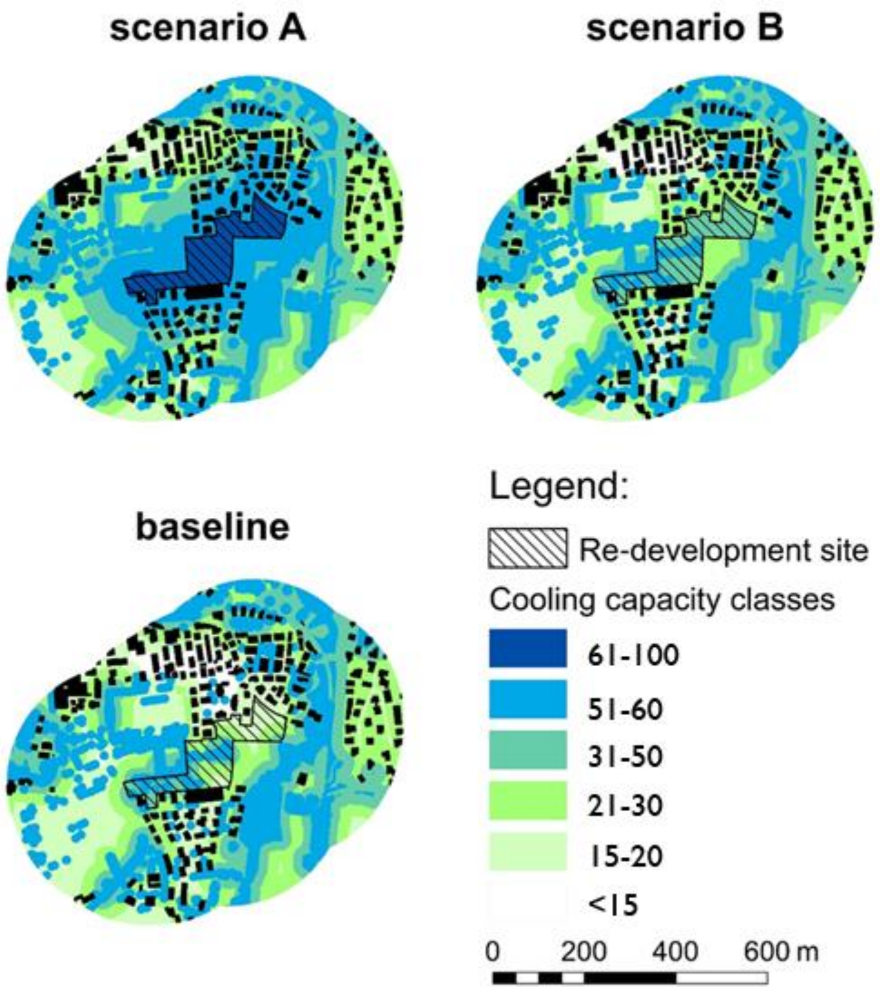

Figure 4.4 Cooling capacity classes modeled for one of the re-development sites (Site 11) in the baseline conditions and under the two transformation scenarios.

Table 4.1 Number of beneficiaries within each cooling capacity class (Site 11, baseline conditions).

cooling capacity score (0-100)	overall population	vulnerable population		
		foreigners	children	elderly people
61-100	0	0	0	0
51-60	255	40	11	73
31-50	376	53	16	108
21-30	725	104	29	201
15-20	938	127	38	263
<15	250	31	11	72

Table 4.2 Number of beneficiaries within each cooling capacity class (Site 11, scenario A).

cooling capacity score (0-100)	overall population	vulnerable population		
		foreigners	children	elderly people
61-100	0	0	0	0
51-60	788	126	30	225
31-50	582	82	23	165
21-30	758	107	32	211
15-20	402	38	19	113
<15	14	2	1	4

Table 4.3 Number of beneficiaries within each cooling capacity class (Site 11, scenario B).

cooling capacity score (0-100)	overall population	vulnerable population		
		foreigners	children	elderly people
61-100	0	0	0	0
51-60	255	40	11	73
31-50	337	45	14	97
21-30	1031	149	40	287
15-20	765	98	33	215
<15	157	22	8	45

As an overall indicator, we used the population and the vulnerable population (i.e., elderly + children + foreigners) affected by the transformation: positive values in the graph indicate a net positive change, negative values indicate a net negative change. The lower graph in Figure 4.5 shows the results normalized by the area of the brownfield, thus providing an estimation of the expected number of beneficiaries per unit of area of intervention.

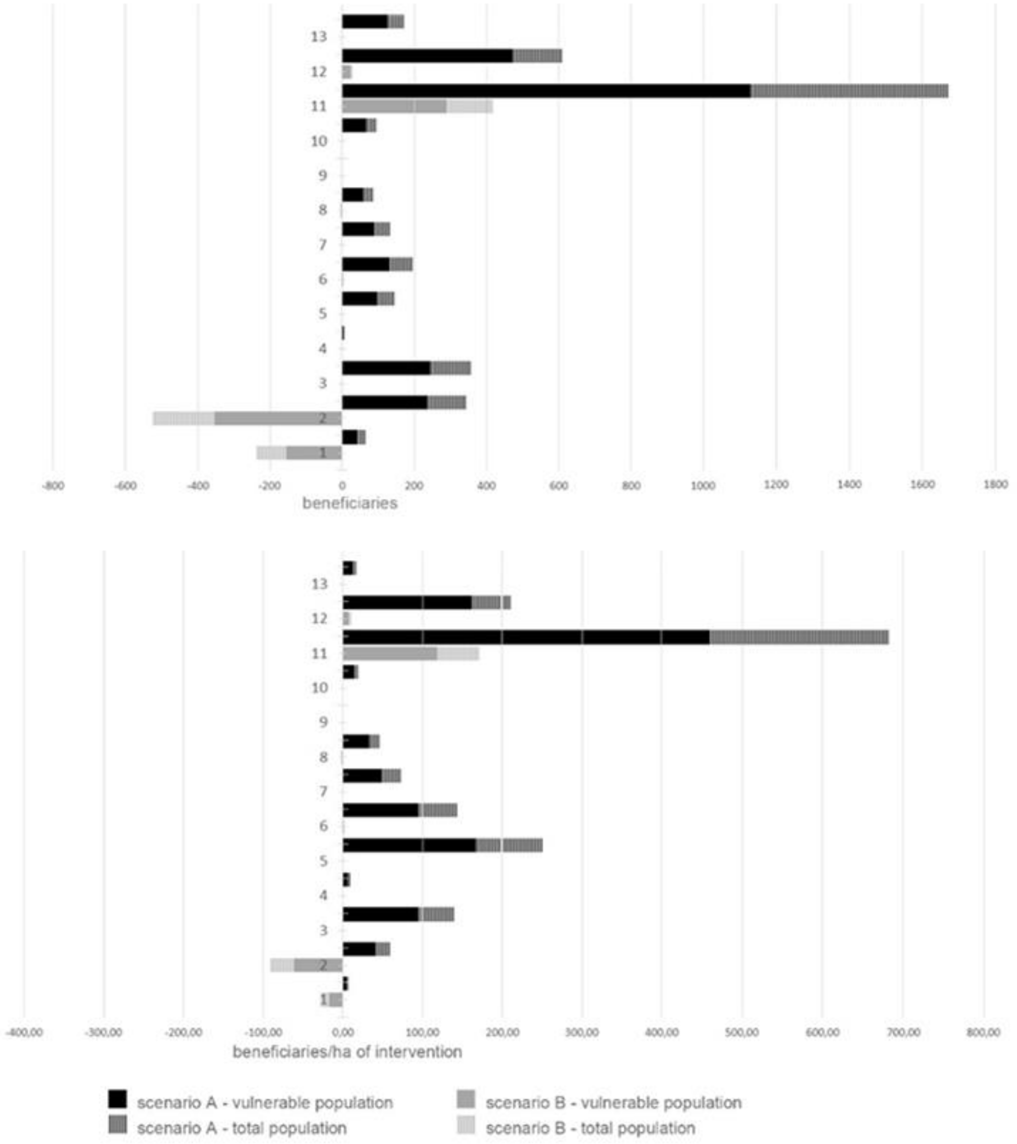

Figure 4.5 Population and vulnerable population affected by the transformation scenarios in each re-development site. Positive values indicate a net positive change, negative values indicate a net negative change in cooling capacity class.

The results of scenario A, which simulates a green area almost totally covered by trees, demonstrate that even a land cover change in a limited area can bring significant benefit to the citizens. Quite the opposite, medium-level interventions (scenario B) are not expected to produce remarkable changes, except for specific re-development sites located inside urban areas with low cooling capacity. Indeed, most of the transformations modeled in scenario B do not generate any benefit for the surrounding inhabitants, whose thermal conditions are mostly determined by other factors (e.g., proximity to other green areas). Only two areas over 2 ha bring some limited thermal benefits to the surrounding residential areas. This is a consequence of the general good conditions of the study area (see Figure 4.2).

Moreover, the comparison permits to identify what interventions are more cost-effective. For example, considering scenario A, re-development site no. 11 produces the best results both in absolute and relative terms, being a potentially large green area inside a heavily built-up and densely populated part of the city. On the other hand, the second rank depends on the indicator: the greening intervention on re-development site no. 12 has a positive effect on the highest number of residents, but the same intervention on re-development site no. 5 performs relatively better, in particular when the number of vulnerable people is considered. This means that, depending on the present conditions of the urban environment and the density and vulnerability characteristics of the resident population, the same investment for greening interventions can be more cost-effective when directed to a small area, even if it results in a lower cooling capacity compared to the one that can be obtained in larger sites.

4.3 Addis Abeba case-study[****]

The booming growth of Addis Abeba simultaneously corresponds to a demographic growth, which trigger an increase in the demand for resources, and a physical growth of the built up that affects the potential supply of resources, from both quantity and quality sides.

“Growing” does not only mean getting bigger, but also getting better. Thus, Addis Abeba plays an important role in promoting the well-being of the country and economic prosperity in the region. For Addis Abeba, efforts to promote greater resilience must be closely aligned with the city’s vision to be a safe and livable city, ensure the national goal of becoming a middle-income country by 2025, and become Africa’s diplomatic capital implying an enhancement of the quality of life. Among the many factors determining the quality of life and wellbeing of citizens, the chance to benefit from a healthy environment plays a crucial role.

Environment in Addis Abeba does not show its best shape. On the one hand, as mentioned, the growing built-up area is substituting the natural capital at a speed of 4 km2 per year. On the other hand, the state of existing green and blue areas in the city is threatened by many drivers, mainly related to the management of resources and basic services such as water and sanitation, drainage and solid waste managements, transportation.

The present state of the environment in Addis Abeba call for major and urgent measures. However, what counts is the trend. The city administration is moving important attempts to address a more environmental-friendly growth. Under the umbrella of the Addis Abeba City

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[****] The Addis Abeba case study presented in this section is based on: UN-Habitat (in print), Addis Abeba City Report.

Report, together with UN Habitat we operated an analysis of the city to provide an overall picture of the state of the environment, with the aim of providing recommendations to the city administration and, in particular, to the panning section.

One of the issues analyzed and presented in the report is the assessments of ES provided by GUI in the city. The analysis aims at identifying priority neighborhoods for action. The criteria of such prioritization combine a fragile state of the environment (poor ES supply) and a high demand for natural resources (high ES demand).

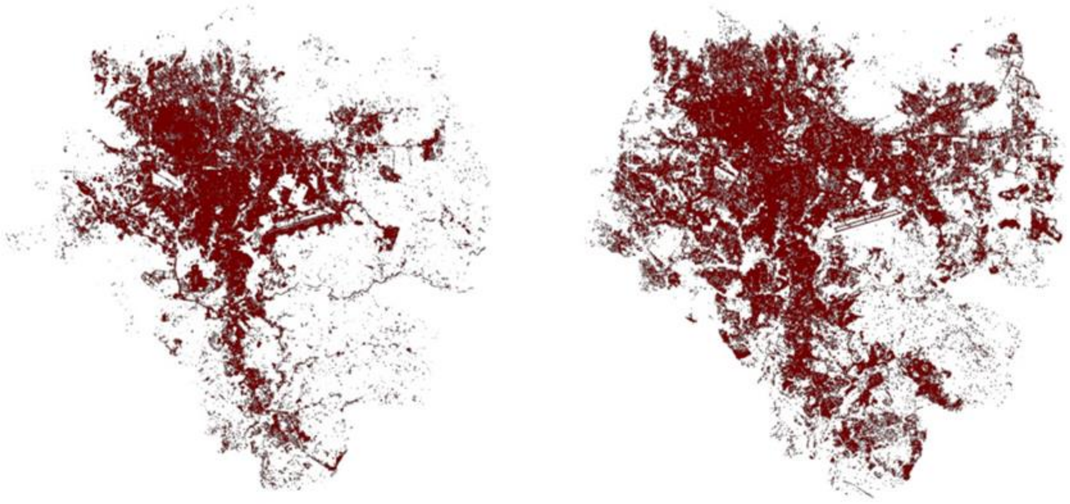

Figure 4.6 The city of Addis Abeba. In red, the built up. Built up area in 1999, 134km2 (left) and built up area in 2014, 201 km2 (right).

4.3.1 Methods

To assess the supply of multiple ES for the city of Addis Abeba, we adopted a method based on land cover as indicator for ES provisioning (McPhearson et al., 2013). We focused on regulating services to cover an often-neglected topic (Frank et al., 2012)). In fact, usually only marketable and tradable ecosystem services (i.e., provisioning services) are considered in decision-making concerning planning and management of resources. We applied the methodology to five ES crucial for the urban environment (Bolund and Hunhammar 1999). More specifically, we mapped the supply for carbon sequestration, carbon storage, air pollution removal (PM10), air temperature regulation, and runoff mitigation (according to the definition of these services provide by McPhearson et al. (2013)).

The ES supply assessment was based on land-cover data. We simplified the HERCULES classification (McPhearson et al. 2013) into four major categories: i) built-up, ii) bare soil, iii) grass and shrubs, iv) trees and forests. We used a land cover map produced by the Civil Service University.

We assigned to each land-cover class an ES supply score from 0 to 10, where 10 corresponds to the best supply possible of that specific ES for the context of Addis Abeba. We applied values adopted by McPhearson et al. (2013) to all ES except for air temperature regulation, which heavily depends on the climatic area. Values for air temperature regulation in Addis were taken from a study by Legese Feyisa et al. (2014). Table 4.4 summarizes the standardized values assigned to each land-use class.

We obtained five maps showing the supply of each of the five ES. We produced a sixth map with the total ES supply in the city considering the average of the 5 ES. Finally, we aggregated values computing the average on a subcity basis to measure the total ES supply in each subcity.

Table 4.4 Standardized values of ES provisioning per soil cover type

	Built-up	Bare soil	Tree and woodland	Grass and shrubs
carbon sequestration (McPhearson et al., 2013)	0	0	10	0
carbon storage (McPhearson et al., 2013)	0	5	10	5
air pollution removal (McPhearson et al., 2013)	0	0	10	4
local climate mitigation (Legese et al,., 2014)	0	0	10	0
run-off mitigation (McPhearson et al., 2013)	0	3	10	6
tot ES provisioning	0	1,6	10	3

The analysis of ES demand was also broken down at the subcity level. We assumed population density as a proxy of ES demand, to avoid the simplistic application of per-capita thresholds that can provide a broad assessment of ES supply for a total city (Larondelle & Haase, 2013) but do not indicate how ES are distributed across different groups of the society. To pursue equitable distribution of ES in the city, we adopted for equity the need-based definition (McDermott et al. 2013): assuming that the people who most need the benefits deriving from an ES are the real beneficiaries of such ES. For the kind of ES we assessed (mainly regulating services), Wolff et al. (2015) affirms that the demand or most needing people are represented by vulnerable individuals and communities. We based our vulnerability indicators on the study of Kazmierczak and Cavan (2011), where they identify four major components of vulnerability among individuals and communities: poverty, children, elderly and foreigners. These four groups are in general more sensitive and present less adaptive capacity in case of stresses or shocks. We excluded “foreigners” since their study was conducted in Europe, while for Addis being “foreigner” does not necessarily represent a disadvantaged socio-economic condition. We mapped the average expenditure per household as a proxy for poverty, and counted the number of people under 5 years old and above 65 years old as children and elderlies. The mapping was done per subcity, by using as source the Poverty Level Assessment of Addis Abeba 2015 for the income and data from the Central Statistical Agency of Ethiopia for the age (Table 4.5).

To obtain an overall demand value per subcity we used the population density value for that subcity and the absolute number of vulnerable individuals per subcity, assigning the same weight to the two factors.

Table 4.5 Demographic data for the city of Addis Abeba, broken down per subcity

subcity	tot population	age (under 5 or above 65)	total expenditure per household
Akaki kality	181270	20064	13448
Nefas silk lafto	316283	34043	10264
Kolfe keraniyo	428895	49361	11059
Gulele	267624	28775	11009
Lideta	201713	20266	8448
Kirkos	221234	21839	12265
Arada	211501	20405	8100
Addis ketema	255372	24739	7227
Yeka	346664	38164	12146
Bole	308995	32294	15550

The supply and demand for ES were calculated independently, then we overlapped supply and demand information to identify where there is high demand and high supply, low demand and low supply, low demand and high supply, and high demand and low supply. This provides a classification of locally determined social needs and the result has the potential to serve as indicator of socio-environmental inequality across the city to identify priority areas for action.

4.3.2 Results

Figure 4.7, 4.8, 4.9, 4.10 and 4.11 shows the maps of the supply of the five ES, namely, carbon sequestration (4.7), carbon storage (4.8), air pollution removal (4.9), runoff mitigation (4.10) and local climate mitigation (4.11). From these maps, it is evident that the major ES supply takes place far from the city center. Thus, it is mainly located outside the city, where the largest and the healthiest ecosystems are located: around the edges, mainly in the North, South-East and a few in the West. Additionally, comparing carbon sequestration (4.87, air pollution removal (4.9) and local climate mitigation (4.11) to carbon storage (4.8) and runoff mitigation (4.10) it emerges that not all ecosystems are warranty of ES supply to the same extent. While the first group pf ES is mainly supplied in the North, the second group of ES is supply in a more homogeneous way within the city boundaries.

Figure 4.12 shows the overall ES supply in the city, obtained by computing an average value among the five ES supply maps of Figure 4.7, 4.8, 4.9, 4.10 and 4.11.

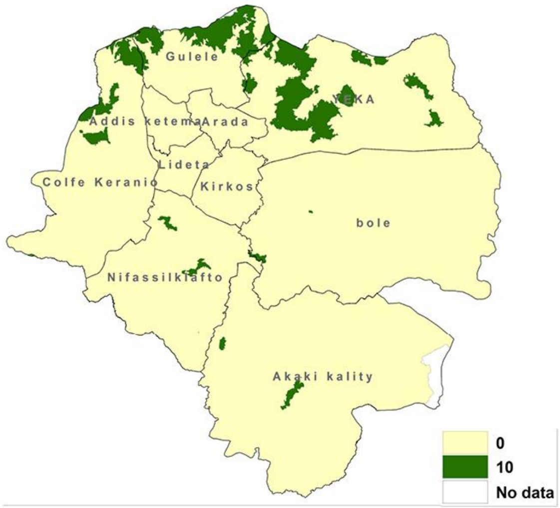

Figure 4.7 Carbon sequestration map for Addis Abeba

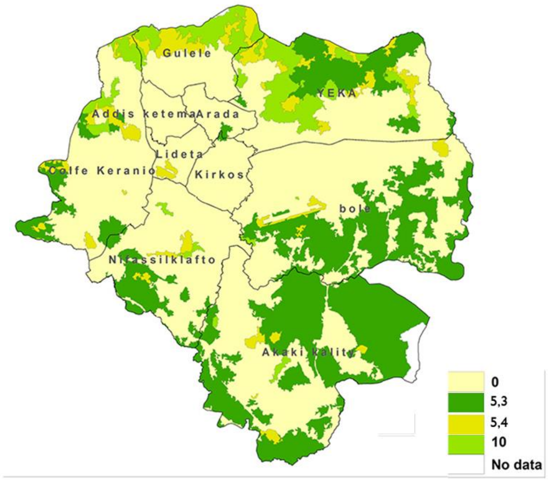

Figure 4.8 Carbon storage map for Addis Abeba

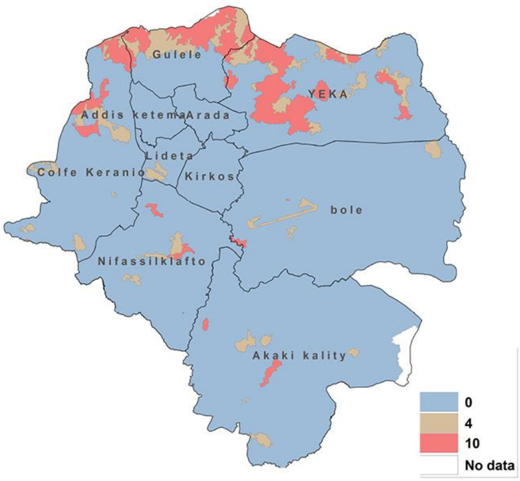

Figure 4.9 Air pollution removal map for Addis Abeba

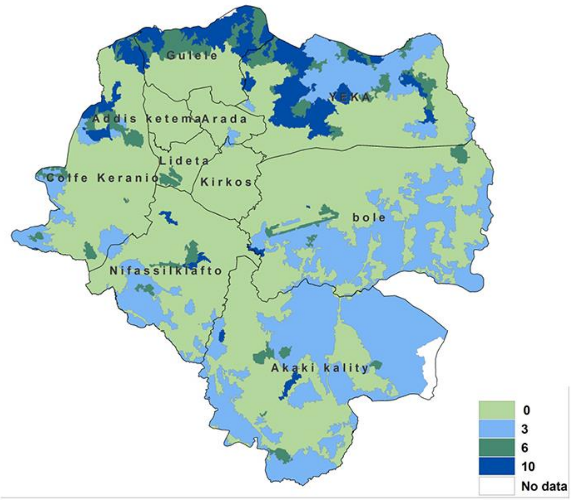

Figure 4.10 Run-off mitigation map for Addis Abeba

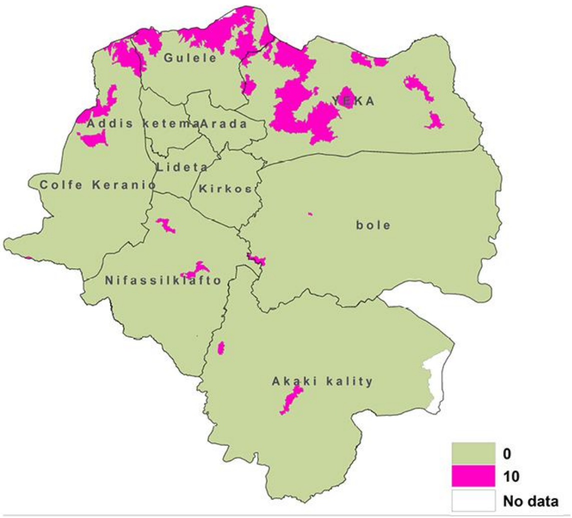

Figure 4.11 Local climate mitigation map for Addis Abeba

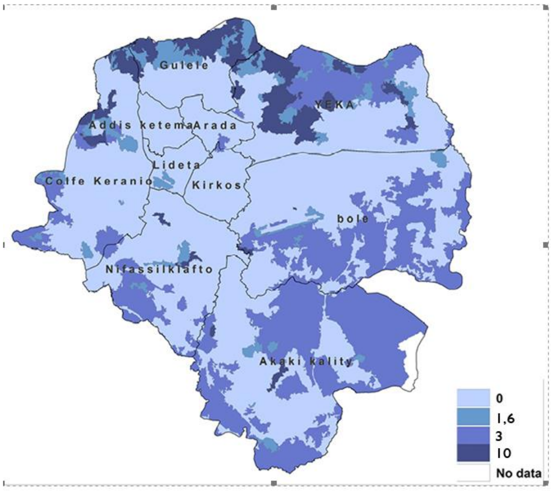

Figure 4.12 Average ES supply in the city

Figure 4.14 shows the demand of ES per subcity. From the map we can observe that the highest demand for ES is required by Addis Ketema –because of high vulnerability and high population density-, followed by Arada and Lideta. Middle scores are shown by Nifassilklafto, Colfe and Gulele. Better situations are represented by Yeka, Kirkos and Akaki Kality, while Bole has the lowest demand score because of the low vulnerability of the population.

The overall supply and demand per subcity scores, standardized in scale from 0 to 10, are summarized in Table 4.6.

Table 4.6 Overall supply and demand

subcity	supply (0-10)	demand (0-10)
Akaki kality	4,5	6,6
Nefas silk lafto	2,0	8,5
Kolfe keraniyo	3,7	8,4
Gulele	**10,0**	8,0
Lideta	0,6	**9,4**
Kirkos	0,1	6,8
Arada	0,4	**9,4**
Addis ketema	0,0	**10,0**
Yeka	**7,9**	7,4
Bole	2,9	4,9

Figure 4.13 shows the overall supply of ES per subcity, summarizing the results of Figure 4.12 and making them comparable with Figure 4.14 –overall demand of ES per subcity-. It is crucial to highlight that the subcity with the lowest supply is Addis Ketema that also shows the highest demand in Figure 4.14: this implies urgent need for action. Kirkos follows Addis Ketema for its low ES supply, followed by Arada, Lideta, Colfe Keranio, Nifassilklafto, Akaki kality and Bole. Best situations are showed by Gulele and Yeka.

The comparison of demand and supply calls for urgent intervention in Addis Ketema, as mentioned, followed by Arada and Lideta, Kirkos.

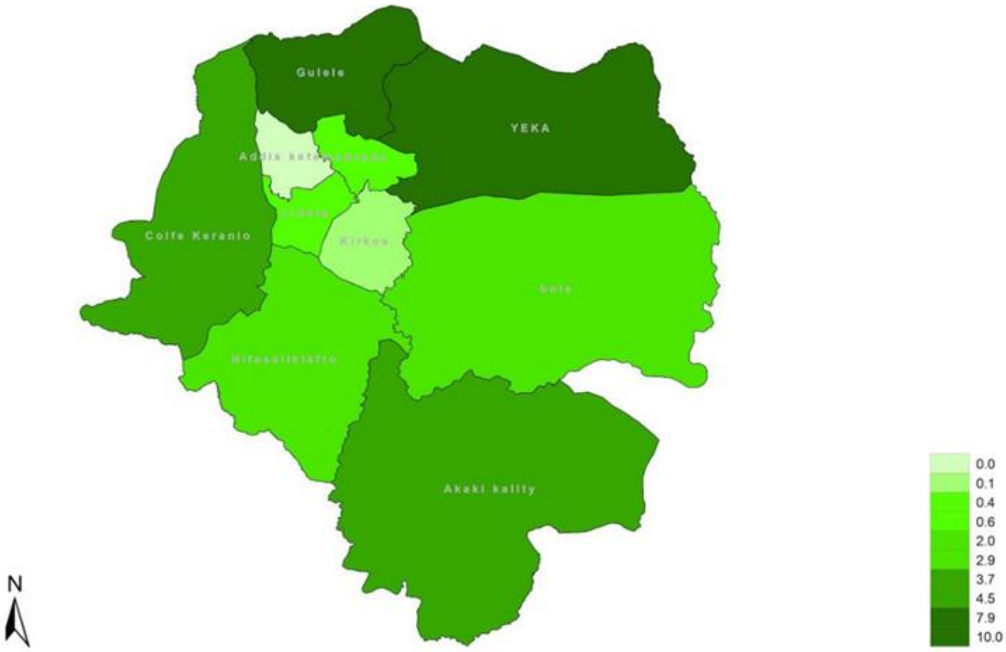

Figure 4.13 Ecosystem service supply per subcity

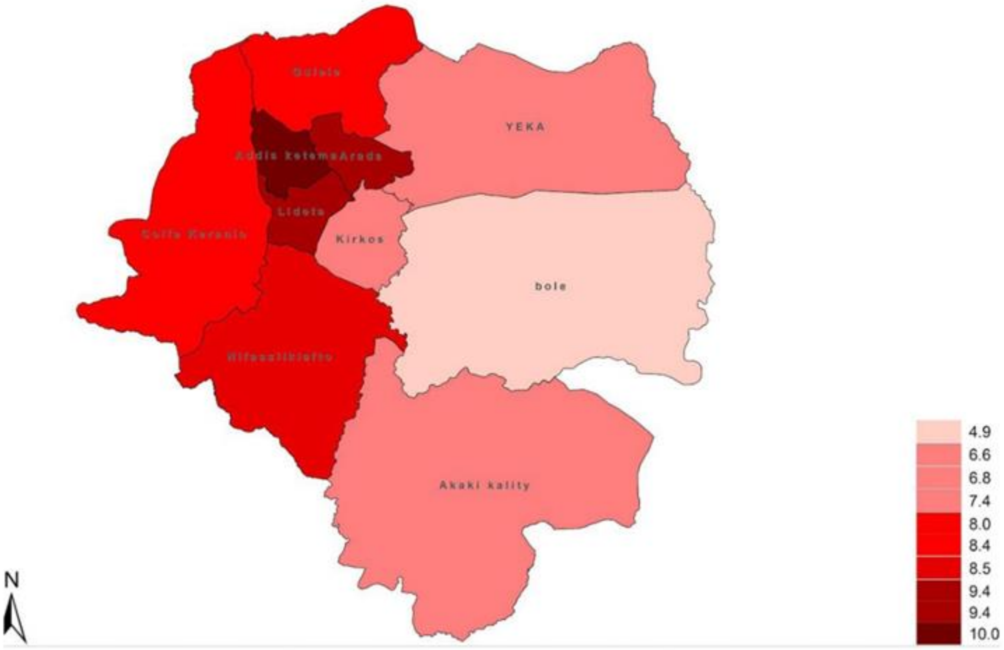

Figure 4.14 Ecosystem service demand per subcity

4.4 Concluding remarks for future research and practice

The application of results from ES assessments to urban planning issues presented in this chapter represents a step in the direction of enhancing the knowledge basis that planners have at disposal to design and implement nature-based solutions that enhance wellbeing in cities. To this aim, urban planning processes can contribute by proposing solutions that maximize the benefits provided by GUI, and by supporting them with an explicit analysis of the expected benefits and beneficiaries.

In the application to the case study of Trento, the explicit consideration of ecosystem service beneficiaries increases the added value provided by ES assessments to decision-making. Additionally, accounting for beneficiaries promotes more integrated forms of urban planning, given that biophysical analyses need to be coupled with socio-economic ones.

Another key area that requires improvement with respect to current practice concerns the analysis of the co-benefits associated with nature-based solutions. While application for Trento focuses only on cooling, the multiple ES assessment applied to Addis Abeba highlights how actions to maximize one ES might trigger synergies or trade-offs with other ES. For example, actions to maximize carbon storage may not correspond to the best interventions to maximize run-off mitigation or air pollution removal (see Table 4.4 and Figure 4.8, 4.9 and 4.10). One of the strongest motivations for promoting nature-based solutions is that they bring environmental and socio-economic benefits, beyond the specific purpose for which they are implemented. On the other hand, they could also compromise the provisioning of other ES, and the presence of such conflicts represent a crucial information for decision-makers.

A more formal analysis of the magnitude of the co-benefits needs to be promoted in impact assessment, in order to provide a stronger rationale for decisions involving the design and implementation of nature-based solutions. Ideally, comparisons between ecosystem-based and more traditional adaptation solutions should be performed, as advocated by Jones et al. (2012). These analyses can take advantage of the methodologies and findings presented in the growing literature on the assessment and evaluation of ecosystem services (Kareiva et al., 2011), including its emerging streams focused on spatial-planning (McKenzie et al., 2014) and impact assessment.

Additionally, the multiple-ES assessment highlighted once more the fact that not all ecosystems provide the same ES and to the same extent. To enhance integration of nature-based solution in urban planning and, more in general, to support urban planning in working with nature, there is need to mainstream information on which ecosystems better provide which ES. Consequently, priority for cities need to be clear during the planning process. The ES literature already moved crucial steps concerning this issue (Figure 4.15): the imperative remains to bridge such understanding with the practice.

In terms of capability of the methods to be applied for planning in real case studies, results from the application were basis for a constructive discussion with the administrations. Specifically in the case of Addis Abeba, the added value of this ES assessment in the process of identification of priority-neighborhoods for environmental actions was crucial.

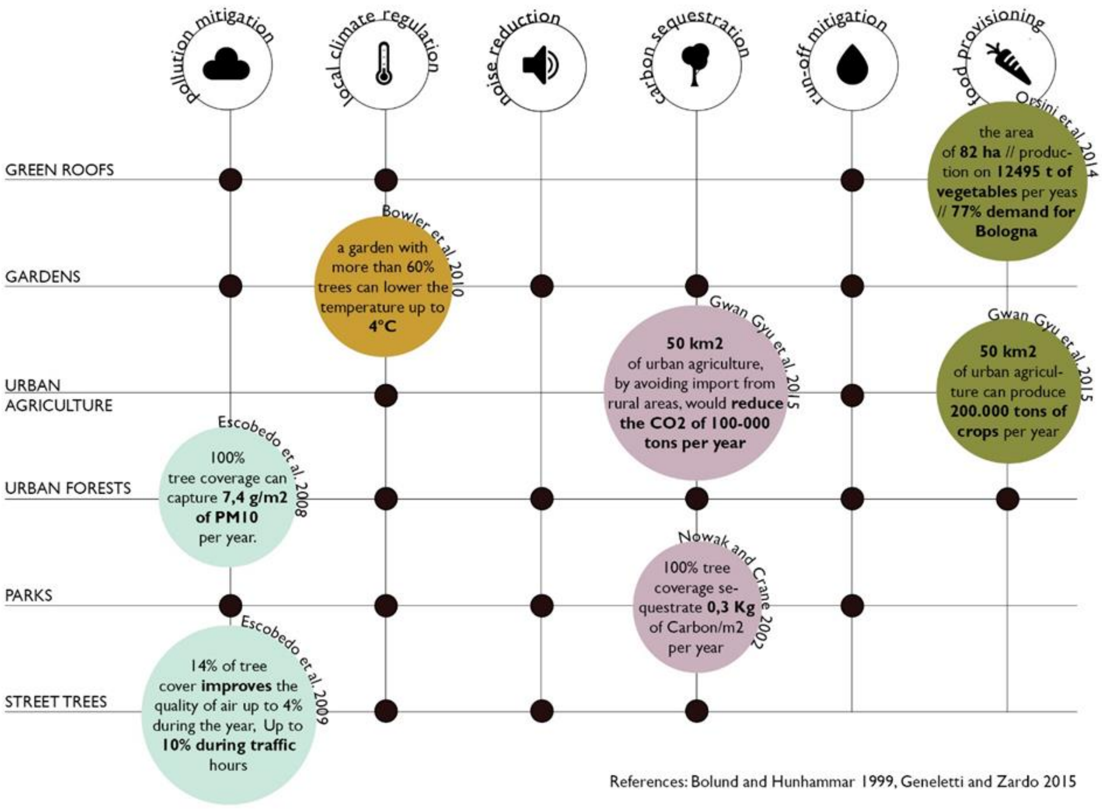

Figure 4.15 Ecosystem-based measures and GUI

Last issue emerging from these two applications refers to proper assessments to analyze the distribution of benefits provided by ecosystems among the citizens. While the application to Trento considers the ES flow in the mapping, the multiple ES assessment for Addis Abeba considers supply areas as proxy for ES. This conception of mapping completely ignores the concept of access. Even though inclusion of information about beneficiaries and demand for ES represents a turning point in the ES assessments, access to ES represents a key element of ES assessments, together with demand and supply, to identify actual and potential beneficiaries. Further research is needed to integrate these three side of the same triangle, and next steps of our work will try to provide a contribution to this aspect of ES assessments.

Chapter 5

Towards an equitable distribution of Ecosystem Services in cities[*****]

5.1 Introduction

The ultimate goal of all plans, programs and policies is human wellbeing. Yet, focusing on the average wellbeing, while overlooking its equitable distribution among different population groups, may result in such plans, programs and policies missing opportunities to effectively address the many challenges facing urban areas. In this respect, the last WCR (UN Habitat, 2016) identified "providing public services in an equitable manner" as one of the major environmental challenges for cities. As Erntson (2013) puts is, the lack of disaggregation in considering distribution of resources provided by the environment obscures the understanding of the multiple dimensions of equitable wellbeing and consequently it avoids equity to happen.

A human rights-based approach to the urban environment emphasizes our universal dependence on healthy ecosystems and abundance of natural resources (UN Habitat, 2016). Thus, among many important factors that determine human wellbeing, ecosystems and their services play a crucial role. In particular, urban ecosystems provide important goods and services that benefit urban residents including habitat for biodiversity, primary productivity, stormwater retention, air pollution removal and heat mitigation (Bolund and Hunhammar, 1999; Gomez- Baggethun and Barton, 2013). However, ecosystems in a city are heterogeneously distributed over space and so do the ES they provide, implying a potential lack of equality in the distribution of benefits among citizens (Ernston, 2013).

Urban planning represents one of the tools administrations have to influence the distribution of ecosystems and ES in a city, to determine the benefits they provide and, more specifically, to re-determine the number, location and type of beneficiaries they reach (Kremer et al, 2013).

[*****] The work presented in this chapter is based on a manuscript in preparation to be submitted to Ecosystem Services

Besides such promising perspective, a majority of present planning practices still apply broad standards, such as per capita green areas threshold values, which can provide a broad assessment of the total ES supply for a city (Larondelle and Haase, 2013), however, failing to indicate the distribution of ES across different population groups.

In fact, if the goal is to achieve an equitably distributed wellbeing, information on the average availability or demand for ES is no longer sufficient. Instead, a proper understanding of the key elements that determine an equitable distribution of ES and their benefits within a city is crucial. This ought to include a level of disaggregation of information that highlights differences within the urban environment. Nevertheless, although equitable distribution of wellbeing, and more specifically of resources –such as ES- in sustainable development and planning is gaining relevance and attention (UN Habitat, 2016), and past research has made progress in mapping important dimensions of equity (Lamorgese and Geneletti, 2015), there are many important gaps still to be addressed. For example, distributive aspects of availability and access to ES are not yet discussed in a sufficient way (Kabish and Haase, 2014). Moreover, we still lack a comprehensive framework that identifies and brings together various dimensions of equity in an integrated, systematic and rigorous way (Mc Dermott). Without a clear definition of which aspects of equity are being pursued and how, it is difficult to evaluate the impact of policies and programs on equity, and impossible to plan for it effectively (mc Dermott). Last, further research is required to clarify equity concerns and operationalize it (Lamorgese and Geneletti, 2015)

A viable approach to overcome the abovementioned barriers would consist of an ES analysis properly designed to bring to surface information that has the nature and accuracy to support equitable distribution of ES. In fact, ES analysis has a huge unlocked potential to support inclusion of equity consideration in the planning practice. Accordingly, the aim of this chapter to contribute to this branch of ES research, by identifying criteria for an ES analysis to provide useful information to pursue an equitable distributed wellbeing, in a real-life practice context.. The chapter unpacks and analyzes three key elements of a complex topic such equitable distribution of ES, namely, i) ES supply, ii) access to ES and iii) ES demand. Starting from the latter, as Wolff et al. (2015) put it, there is no way to assess equitable distribution of ES in a city without having cleared whatthe demand is, and who should get priority in benefitting from ES.ecause ES benefits depend so critically on the spatial configuration of both ecosystems and people, a spatially explicit approach to ES assessment is essential to achieving the benefits of an ES framework (Mandle and Tallis, 2016). Thirdly, having identified and assessed the demand side, to assess whether equitable distribution is pursued, we need to quantify the supply of the ES both in terms of their biophysical supply and in terms of accessibility. As put by Tallis and Polasky, (2009), in fact, without ES supply nor access to it there can be no benefit and no beneficiaries

Yet, equitable distribution of ES represents only one of the multiple dimensions of equity in the environmental and planning context. The broad concept of environmental equity calls in fact for equal access to clean environment and equal protection from possible environmental harm irrespective of race, income, class (Schwarte & Adebowale, 2007). Equity is not just a general principle but a comparative concept: it is principally concerned with relationships between people, and with their relative circumstances" (Grasso, 2007). In general, three dimensions define the essence of equity: distributive equity focusing on fair allocation of ecosystems and the ES they provide, procedural equity relating to fair integration in planning and decision processes of all social groups, and interactional equity dealing with the quality of interpersonal relations in a specific place (Low, 2013).). In this chapter, we focus on the distributive dimension of equity and pursue equitable distribution of ES, assuming that sustainable planning can contribute to investigating the distributional dimension of equal provisioning of ES. More specifically, we opt for an "equitable distribution of ES", which is a need-based definition, shared by a diverse set of theorists from John Rawls (1971) to Karl Marx. Operationally, to pursue equitable distribution of ES in a city, we assume that the people who most need the benefits deriving from such ES are the real beneficiaries of such ES. As a final remark, in this chapter we focus on regulating ES, which – despite their importance for climate change adaptation in cities and, in general, for urban wellbeing, still remain to be poorly investigated (Haase et al., 2014; Luedeitz et al. 2015).

The remainder of this chapter is organized in x sections. Section x.2 investigates the existing literature to identify criteria for supply, access and demand analysis to be proper support for an equitable distribution of ES. Section x.3 presents the case study and the here proposed methods assessing disaggregated supply, access and demand analysis; hence, for aggregating the results to explore ES distribution in the city. Section x.4 presents the results from the supply, access and demand analysis as well as results of the overall distribution of ES analysis. Further, we compare our results with those form alternative assessment framework that do not explicitly account for an equitable distribution. . Finally, Section x.5 and x.6 present critical discussions about our findings and draw some general conclusions, respectively.

5.2 Criteria for analysing functional to equitable distributon of ES

An outstanding advantage of the ES approach is that it shows the conditions under which nature creates benefits. Scope of this section is to highlight declared gaps in existing analysis of ES supply, access to ES and demand for ES to properly support the equitable distribution of ES in urban context. Thus, the leading question of this section is "how should this analysis be designed to support equitable distribution of ES in a city?"

The criteria identified in each of these subsections are summarized in Table 5.1.

5.2.1 Criteria for a supply analysis

When environmental equity mentions the right of all people to a clean environment, this right goes beyond the simple requirement of an amount of green per capita. Even though nor the ES supply concept expressed by De Groot et al. (2002) and not even the majority of planning policies describe how spatial relations between supply side and demand side are taken into account, it is crucial that ES analysis addressing equity identifies where ES are supplied (Burkhard et al. 2012).

To address such supply spatial distribution, many studies assess equitable distribution of green areas and the ES they provide in urban context, adopting the spatial distribution of green areas as proxy of the spatial distribution of the ES they provide. When taking into account and mapping areas providing ES, the use of public green areas as proxy of ES supply, unfortunately, overlooks the accounting of all ES provided by other ecosystems in a city such as private gardens, street tress . Additionally, all ecosystems in a city have shown to provide environmental benefits such as ES, but according to their structure and physical characteristics, any ecosystem provides different types of ES and with different extent of effectiveness (De Groot et al., 2010). This is crucial when addressing equitable distribution of ES human wellbeing, because different ES contribute to different aspects of wellbeing (Daw et al., 2011). Furthermore, due to lack of data, ES supply is often described in an aggregated form; however, such aggregated quantification of ES does not elucidate implication of having a park instead of street trees, for example. Considering all green areas as equal black boxes providing ES -without being able to determine which ES and to which level of effectiveness is each ES supplied-, represents a poor starting point to address issues of equity (Daw et al., 2011).

In this respect, the ES assessment literature can indeed provide a substantial contribution to overcome this gap. Several studies provided tools for better capturing ES supply by different kind of green area, applying synthetic proxies such as land cover to consider multiple-indicators per each ES (e.g. Dobbs et al., 2011; Burkhard et al., 2012; Kremer et al., 2013; Derkzen et al., 2015). It is crucial to remember here that, despite data availability may represents a key issue, ES indicators should relate to pertinent scale resolution. For example, when performing an equity assessment of ES distribution in a city, using regional land cover maps to map the ES supply may lead to misleading results.

To conclude, to effectively capture ES supply to provide useful information for equitable distribution of ES, the assessment should consider all ecosystems in the city, not only public green spaces. Additionally, the assessment should be able to provide a disaggregated information about the extent to which different ES are provided by ecosystems, instead of providing one total ES amount value or not to specify which kind of performance different areas can present in ES provisioning. Goal of an ES supply analysis to support distributive equity should be to identify where the variety of ES services are generated, what the underlying spatial structures are, and to which extent?

5.2.2 Criteria for an access analysis

The direct comparison of ES supply and demand in spatially explicit maps is rather rare in spite of the wide agreement about the importance of including demand side into ES assessments (Burkhard et al., 2012). Still, when this kind of studies are carried out, they assume that the demand is satisfied if overlaying demand and supply analysis there is a match, without considering if the demand can access such supply (e.g Burkhard et al., 2012). Syrbe and Wal, 2012 .). Assessing the access to ES provisioning is crucial to determine who are the beneficiaries of the ES (Tallis and Polasky, 2009) and if institutions restrict the ability of beneficiaries to access the ES supply, then there is no benefit. If people cannot physically access ES that require such access then no human benefits can accrue either (Tallis and Polasky, 2009).

While Tallis and Polasky (2009) explicitly refer to access to ES supply, in the planning practice, the tendency however is to apply access to green public spaces or green areas as a proxy of ES supply. Access to ES is different from access to ecosystems or, even more limitative, access to green public spaces. Such approaches do not take into account the fact that some ES are transportable or can reach areas outside the area of ES generation itself (Syrbe and Wal, 2012) up to some hundreds meters (e.g. local climate regulation, Zardo et al., submitted). This is particularly true for regulating ES (Fisher et al., 2009) for which the mismatch between the spatial distribution of green areas and the spatial distribution of ES supply can trigger misleading analysis and consequently negatively affect decision-making.

Even in recent literature, despite access to ecosystems and the ES they provide has become recognized as an environmental equity issue (Dai, 2011; Jennings et al., 2012) there is no consensus among scholars about how to measure such access (Wolch et al., 2014). The literature has mainly focused on how to measure access to green public spaces, primarily parks. Most studies have used Geographic Information Systems (GIS) to measure accessibility (Oh and Jeong, 2007; Sister et al., 2010; Talen, 1997). The metrics used include presence vs absence of a park or recreation facility near residential areas, density of facilities, or total park acreage within a given radius from houses (Mota et al., 2005; Norman et al., 2006; Roenmich et al., 2006).

However, geographic access alone may not fully capture the access to such ecosystems (Wolch et al., 2014). As mentioned earlier, also institutional access should be considered, given that if formal (laws, regulations) or informal (social norms, cultural practices) institutions restrict the ability of beneficiaries to access the ES supply, then there is no benefit. In this respect, it is highly challenging to capture and quantify informal institutional barriers to access, while formal access to green areas have been assessed using property rights as proxies (private VS public green space). Furthermore, such information still is not enough to capture the real access to the ES supply; in fact, regulating services can go beyond the physical limits of their supply area (e.g. cooling) (Fisher et al., 2009). There is thus a need to assess the access by first to expliciting the spatial distribution of the ES supply, which in turn varies depending on the type of ES.

A highlighted in Syrbe and Wa (2012), demand and supply of ES might spatially overlap to some degree, with the possibility of having some gaps. Defining whether access to ES occurs or not, requires in fact considerations of the flows of ES, as well as the physical and institutional ability of people to access those benefits. In this chapter, to define the flow of the four illustrative ES, we refer to the concept of "benefitting area" introduced by Syrbe and Wal (2012). Benefitting area is the real area of influence of the ES supply, and as such, it provides a better basis to access assessments (Syrbe and Wal (2012). Yet, the ES supply flows across the landscape (Fisher et al., 2009), so that we need spatial characteristics of ES (e.g. their scale, direction of flow, if benefit depends on the proximity to the ES etc.) to describe relationships between the supply of ES and where the benefits are realized (Fisher et al., 2009). In other words, there is need to map the ES itself instead of the area providing it.

In conclusion, if the goal is to assess the access to the ES, and not just the access to ecosystems that supply the ES, first, it is crucial to define the flow of the ES. This implies spatial consideration in terms of scale and direction of ES (Fisher et al., 2009). More specifically, there is need to characterize how the flow of each ES occurs and whether the benefits depend on the proximity of beneficiaries to the ES flow. Eventually, it would be crucial to understand the role of the scale and direction of the flow as well as that of possible physical or institutional barriers to access such flow.

5.2.3 Criteria for a demand analysis

The analysis of the demand is equally crucial to inform decision-making and planning, thus the importance of research aiming at a better understanding of the concept of demand itself and its many implications (Wolff et al., 2015). Despite this, while several ES studies analyzed the supply side, only a few values the demand side (Larondelle and Lauf, 2016). At the same time, call for holistic accounts of people and nature is coming from both governmental and health organizations (Tallis and Polasky, 2009); yet, in the most common conceptual frameworks of ES, demand is not explicitly indicated (e.g. Haines-Young and Potschin, 2013; MEA, 2003). When included, a common practice to consider demand as equally distributed among all citizens, fixing a standard threshold of "urban green area per capita" (Kabish and Haase, 2014) or relying on population density as proxy for demand, with no consideration of socio-economics differences among individuals in a city. Equity does not require everybody accessing the same types, and amount of ES, nor can be addressed by considering all people as a whole (Mc Dermott et al., 2015).

Indeed, some good examples of ES demand assessments do exist including the review on demand by Wolff et al. (2015) or the mapping and assessments by Stürck et al. (2014), Schulp et al. (2014), Paracchini et al. (2014)., and Baró et al. (2015). However, most of these studies aggregate the perspective of humans and their wellbeing, which can be misleading in terms of pursue of equal wellbeing. In fact, different groups derive wellbeing from different ES, individuals or groups present different needs for a same ES and not all people need the same ES (Rodriguez et al. 2006). There is need of disaggregated view to inform decision-making, explicating who derives benefits from what. On the other hand, hundreds thousands options do exist for targets, which makes the design or a demand assessment challenging. Additionally, in a recent study van der Biest et al. (2015) research the accuracy of different approaches using a coarse thematic resolution, and "while these methods are powerful awareness-raising instruments, applying them on the level of decision-making may have adverse effects" (Van der Biest et al., 2015) as the spatial resolution often proves to be not fine enough.

Setting criteria to operationalize a demand analysis functional to pursue equitable distribution of ES becomes methodologically important (Wolff et al., 2015). As mentioned above, Mc Dermott et al. (2015) states that the criteria to target the demand should be the need for ES. More specifically, the target, the "who counts for equity", needs to uncover which social groups or individuals need ES and such assessments will involve comparing capabilities of individuals, costs, benefits, risk, opportunities, and factoring variables like gender (Sen, 2009).

To consider demand for equity, it is equally crucial to identify the "who" –the target for demand-, and where such demand is located (Mc Dermot). This means we need to account for the fact that not only the supply of ES but also the needs of people are heterogeneously distibuted over space. To consider this is methodologically important because there is need to explain spatial relations, consider them in the valuation process; adopting indicators with pertinent spatial resolution.

Table 5.1 Criteria for supply, access and demand analysis

	Supply	**Access**	**Demand**
The analysis should satisfy these CRITERIA:	i)Consider all ecosystems in the city, not only public green spaces. ii)Provide disaggregated information about ES supply, instead of providing one total ES amount value iii)Specify to which extent different ES are provided by ecosystems, Specify where the variety of ES services are generated	i)Consider access to ES, not to ecosystems or public green spaces ii)Identify the flow of the ES If benefitting from that ES depends on proximity, identify scale and direction of the flow iii)If benefitting from that ES depends on proximity, identify if there are physical or institutional barrier to access the ES flow.	i)Consider the "who" –the target for demand ii)Consider where such demand is located

5.3 Methods

5.3.1 Case study: Trento

The study area is in of Trento, a city located in an alpine region in Northeastern Italy. Trento is a middle-size city that sprawls about 10 km across the Adige Valley floor. Despite its limited size and the presence of big surfaces of forests outside the city, being located in valley, Trento suffers of high temperature in the summer and air pollution and noise can represent a problem due to the presence of the train rail, the motorway and other important roads.

For our analysis, we selected four sample areas (500m per 500m size) representative of different condition within the city (see Figure 5.1). Our aim here is to score and compare the differences between the sample areas in term of supply, demand, access and equitable ES distribution. The size of the sample areas is following by McPhearson et al. (2013), who assume 500m to be the average size of a neighborhood. Whereas the selection of the four samples, this is based on two criteria. First, all areas have to belong to the residential tissue of the city; in fact, all four sample areas belong to the central part of the city, where population density is higher and presence of public green spaces and ecosystems in general is limited. Second, each sample area should represent a different demographic environment. Accordingly, sample area 4 is an area mainly populated by elderly, while sample area 3 is an area for relatively low-income households and with a higher percentage of immigrants compared to the average for the center of the city. Sample area 2 belongs to the historical part of the city, where houses are expensive, while sample area 1 is a newly built neighborhood with no specific demographic connotation yet.

For all the three analysis presented is section 3.2 (ES supply analysis), 3.3 (Access to ES analysis) and 3.4 (Demand analysis) we adopted exiting methods or merged pieces of existing methods to obtain analysis that satisfy criteria mentioned in Table 5.1.

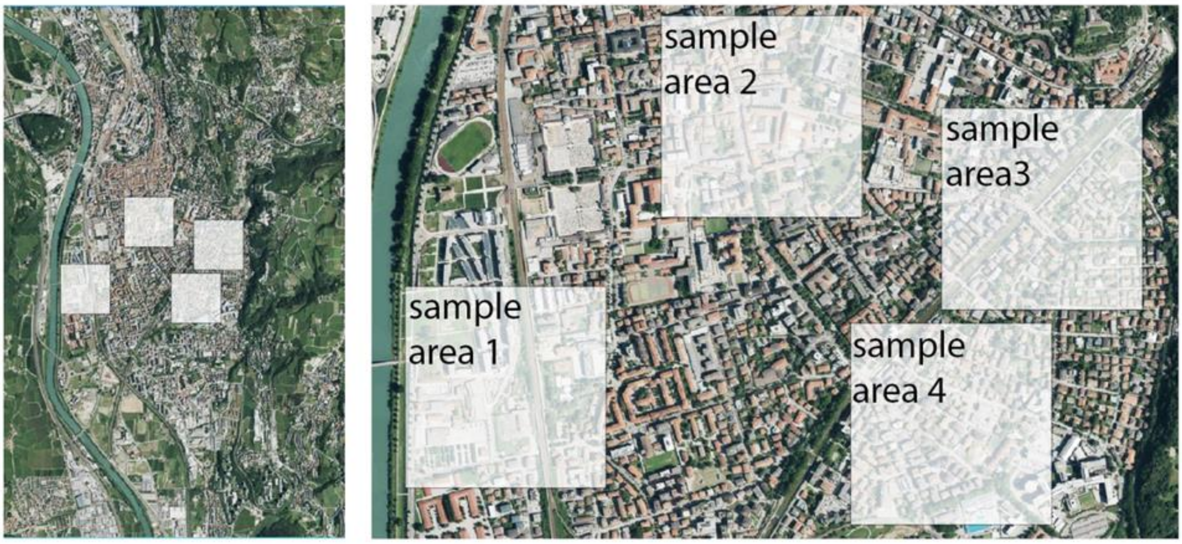

Figure 5.1 Sample areas

5.3.2 Supply analysis

We selected four regulating ES based on the benefits they potentially provide in terms of human health and well-being in cities: carbon storage, air pollution removal, local temperature regulation, noise mitigation. We consider carbon storage ES as gross aboveground carbon storage and consider the amount of carbon stored rather than its dynamics in time. We consider air pollution removal as the lowering of background air pollution concentrations; we focus on PM10 because it is most harmful to citizens' health and most effectively captured by urban green. (Derkzen et al., 2015). We consider cooling as the capacity vegetation to lower air temperature though shading and evapotranspiration. We consider noise mitigation as the physical capacity of vegetation to attenuate environmental noise.

To assess each of the four ES, we mutuated indicators from the works by McPhearson et al. (2013) and Derkzen et al. 2015. Both these works did a review of the literature to identify indicators to quantify ES supply of different ES in urban areas (see Table 5.2A). More specifically, to quantify carbon storage indicators supply by ecosystems in the city we adopted carbon storage indicators provided by McPhearson et al. (2013) for the city of New York. To quantify air pollution removal, again we adopted indicators provided by McPhearson et al. (2013), focusing only on PM10 removal indicators. For cooling we adopted values from a study that investigate the cooling capacity of ecosystems based on multiple indicators and considering different climatic regions (Zardo et al., submitted): in this way we could provide values more accurate for Trento (we took cooling values for Csa region –Koppen Classification- provided by ecosystems below 2 hectares). To quantify noise reduction we adopted indicators provided by Derkzen et al. (2015) for Rotterdam.

All indicators were harmonized according to four land cover types–namely, i) built-up and sealed, ii) bare soil, iii) grass and fine vegetation, iv) trees and woodland-. Table 5.2A shows the collection of indicators. Then, all indicators were rescaled from their organic unit into a standard scale of 0–10, where 10 is the highest occurring value of an ES, and all other values normalized to a 0–10 scale (see Table 5.2B).

Table 5.2 Soil cover indicators for ES supply

Table 5.2A	Built-up	Bare soil	Tree and woodland	Grass and shrubs
carbon storage (McPhearson et al., 2013)	-	8.2 kg/m2	15.5 kg/m2	8,4 Kg/m2
air pollution removal (McPhearson et al., 2013)	-	-	2.73 g/m2/year	1.12 g/m2/year
local climate mitigation (Zardo et al,., submitted)	-	1.2°C	3.6°C	1.2°C
noise (Derkzen et al., 2015)	-	-	2Db (A) 100 m^-2	0.375 (A) 100m ^ -2

Table 5.2B	Built-up	Bare soil	Tree and woodland	Grass and shrubs
carbon storage	0	5,3	10	5,4
air pollution removal	0	0	10	4
local climate mitigation	0	3,3	10	3,3
noise	0	0	10	1,8

The land cover types of our sample areas were collected by visually inspecting the orto-photo of the sample areas and by manually mapping the four land cover types with QGIS. The land-cover information for the sample areas was combined with values from table 2b to obtain the supply map of each of the four ES.

To conclude, to obtain an overall score of ES supply, for sample area and for each ES, we multiplied the surface (m2) of each specific land-cover for its supply score (0-10) from table 2b. For air pollution only, considering that the literature assigns double effect, a double air-pollution removal supply score, to urban green located in a distance of 50m buffer from the streets compared to the urban green out of this distance-buffer, we assigner to the green areas inside a 50m buffer from streets the values in Table 5.2B and to urban green outside such buffer have the scores (e.g. a tree next to the streets has a air pollution removal supply of 10/10, while if it I more far than 50m its score is 5/10). We summed the four results and divided them by the overall surface of the sample area (250000 m2). The result is a ES supply score from 0 to 10 for each ES for each of the four sample areas.

5.3.3 Access analysis

To assess whether access to an ES occurs or not, firstly, we need to define the flow of the ES and, secondly, in case the benefit of the ES depends on the proximity to the ES itself, we need to define how access to the ES occurs.

In the remainder of this section, I illustrate the methodology applied for mapping the the flow of the four ES considered in this work, starting from their spatial characteristics as described in the literature:

•Carbon storage. Costanza (2008b) defines carbon storage as “global-non proximal” ES, meaning that the benefit of the service does not depend on proximity, since the spatial location of carbon storage does not matter. Thus, for carbon storage the supply is usually assessed not locally but rather regionally or globally (Derkzen et al. 2015). However, although the contribution of ecosystems in cities in overall carbon storage is relatively small and undervalued in national assessments, its potential as a carbon reservoir is significant (Hostetler and Escobedo, 2010). Cities can act as carbon sinks and thus contribute to global carbon storage in a small but considerable amount (Strohbach et al., 2012). For these reasons, the spatial distribution of carbon storage is here considered as equally distributed through space in the city, as average value resulting from the contribution of the different ecosystems in the whole city. In this specific case, we will keep as average value the one resulting from all green areas in the four sample areas.

•Air pollution removal. When defining scale of relevance of ES, Demuzere et al. (2014) consider scale of air pollution removal to be the most unclear of the benefits studied. Air purification services can vary significantly depending on specific characteristics of green spaces such as tree type and the location of vegetation in relation to buildings, and effects of this service have been demonstrated only on a site/block scale. However, the evidence is not particularly strong as it is dependent on case-specific local characteristics and general conclusions are difficult to justify. Thus, for this reason, air pollution removal assessments in cities have mostly been based on mean values for an entire city (Escobedo and Nowak, 2009), considering that, when dealing with background pollution, air pollution removal’s effect is considered to be non-dependent on proximity (Derkzen et al., 2015). On the other hand, Escobedo adds that air pollution removal function by urban vegetation should vary because of this spatial heterogeneity and shows with his studies about Santiago (Escobedo et al. 2008; Escobedo and Nowak, 2009) that even dealing with background concentration, the variation can be perceived at district/neighborhood scale (100-10000 m). For these reasons, the spatial distribution of air pollution removal is here considered as equally distributed through space in the neighborhood, as average value resulting from the contribution of the different ecosystems. In this work, for neighborhood we consider the sample area-size (500m x 500m), coherent with the neighborhood size defined by McPhearson et al. (2013).

•Cooling. The work by Demuzere et al. (2014) shows the influence of such ES to belong to the site-block scale, with uncertainties about the district-neighborhood scale. Costanza (2008b) defines cooling as a local and proximal ES, while in terms of spatial distribution its behavior can be considered omnidirectional, meaning that the effect of cooling determined by a green area can reach a distance of some hundred meters all around the green area itself. Urban green has a cooling effect that lessens with increasing distance and depends on surface area, vegetation type and spatial conjunction (Xie et al. 2013); consequently, it is hard to assign a fix buffer of influence to it. However, the cooling effect estimated for areas smaller than 2 hectares is perceivable up to about 100 m out from the site (Shashuabar and Hoffmann, 2000). To conclude, considering that Trento is a small city, with the high majority of green areas smaller than 2 hectares, in this work we map the cooling effect of green areas with a buffer of 100 m, assigning it half the cooling supply score of the area that determines it. Such effect is mainly due to evapotranspiration. Additionally, to consider the local contribution of shading by trees mentioned by Taha el al. (1991) and Akbari et al. (1992), we add a buffer of 5 meters to the canopies with the cooling supply score of trees.

•Noise Reduction. Urban ecosystems provide noise reduction services by serving as natural sound buffers (Van Renterghem et al., 2012). Vegetation provides both a direct and an indirect barrier to environmental noise (Derkzen et al., 2015). Applying the ES classification given by Costanza (2008b) into categories according to their spatial characteristics, we can define noise reduction as proximal (it depends on proximity) and directional flow related, meaning that the direction of the ES spatial distribution depends on the location of the source of noise (in these case, streets). According to the results of a research by Samara and Tsitsoni (2010) the largest reduction, 6 dB, was seen in 60 m away from the road. Of course, as mentioned in the methods, both the intensity of noise reduction and spatial extension of the ES depend on the structure of the trees and on how big the row or belts are (e.g. spatial visibility, typology of trees, age of trees, …) (Fang and Ling, 2003). Derkzen et al. (2015) also confirm that most noise reductions are measured up to a distance of 50 m from the road. For these reasons, we consider the spatial distribution of noise reduction with a buffer of 50m from the ecosystem, with direction opposite from the source of noise (roads) and with a noise-reduction supply score that is half compared to the noise reduction supply score of the area determining it.

At this point, the flow of all four ES are mapped. When considering “access to green space” (Barò et al., 2015), and equity of access, many studies introduce the dimension of property, distinguishing among public, common and private spaces. For this analysis, we only consider non-private areas of each ES flow.

Thus, this work consider wants to assess the availability of services for all residents living in the sample area. For this reason, we use property (public vs private) as proxy of both physical and institutional access to the ES flow. Additionally, we assume that being the sample area of 500m x 500 m all benefits are physically accessible meaning that they are at a walkable distance (Kabish and Haase, 2014).

Given that only two services (cooling and noise reduction) depend on proximity, we here analyze the physical and institutional access through property only for these ES, while for the other two ES (carbon storage and air pollution removal) we consider them to be equally accessible within a sample area. Finally, to obtain an overall score of ES access, for sample area and for each ES, we multiplied the surface (m2) of flow for its supply score (0-10), avoiding m2 of benefitting areas in private areas for cooling and noise reduction. We summed the results for each ES and sample area and divided them by the overall surface of the sample area (250000 m2). The result is an ES access score from 0 to 10 for each ES for each of the four sample areas.

5.3.4 Demand analysis

With respect to identification of groups and individuals that most need ES, there are two options. Depending on the type of ES, the need can be assessed based on either the direct use of an ES in the past or on the desirable supply of an ES (Wolff et al., 2015). When considering regulating service, the assessment is usually done by using desirable ES supply and, more specifically, the indicator to identify such demand is vulnerability (Wolff et al., 2015). Thus, demand for regulating services is represented by vulnerable individuals (Wolff et al. 2015).

Kazmierczak and Cavan (2013), investigating the vulnerability of individuals and communities to hazards, state that vulnerability of people is function of characteristics of people, which influence their access to information, their ability to prepare for, respond to and recover after hazards. The indicator they used to assess vulnerable groups are: poverty, diversity (presence of foreigners), children (0-4 years old) and elderly (above 65 years old) (Kazmierczak, 2012).

For the vulnerability analysis in this chapter, I adopt three out of the four indicators suggested by Kazmierczak, (2012). The poverty indicator is left out mainly because the related data (e.g. income or household’s expenditure) is publically available only in terms of average values for the whole city. On the other hand, socio-economic spatial-localized data for children, elderly and foreigners was obtained from the public administration at the resolution of data per census cell. Census data provided by the municipality about total number of residents, age group distribution, and presence of foreigners for each census block have been collected and linked to the spatial map. To be as accurate as possible in the spatial definition of the population, we identified the residential buildings inside each census block and distributed the residents only in the surface covered by their footprint.

From this process, we obtained the total number of vulnerable per each of the four sample areas. We could not know whenever there was overlapping between vulnerabilities (e.g. an old person can also be a foreigner), but we just counted any vulnerable as one unit, considering that an individual both old and foreigner or the presence of one old and one foreigner would equally raise the vulnerability of the neighborhood.

To conclude, to assign an overall score of ES demand, we just normalized the absolute numbers of vulnerables of each sample areas to obtain a score from 0 to 10.

5.3.5 Analysis of equitable distribution of ES

This section illustrates how the results from the supply analysis, access analysis and demand analysis are combined to gain an overall idea about distribution of resources and need for them and equity of such distribution among sample areas. Starting from the supply, access and demand scores, the results are aggregated to analyze the equitable distribution of ES. More specifically, I only consider scores from the access analysis and the demand analysis because in my approach the access analysis and its scores already include supply scores.

To aggregate them, I divide the access score by the demand score per sample area, per ES. The higher the score is, the better it is. However, high or neutral score do not imply that the demand for ES is satisfied. This is an analysis about the distribution of ES, access to such ES and demand for them in the city. For this reason, this final score allows the user to create a ranking among demand present in different areas of the city and access to ES, in relative and standardized way. So high scores for demand means that demand of the city is particularly located there, same for supply and access. This represent a powerful tool to highlight mismatches in terms of supply and demand distribution.

As a last exercise, I compare scores for equitable distribution of ES obtained through this last subsection of the methods, with alternative analysis of equitable distribution of ES that do not follow all the criteria we listed in Table 5.1. More specifically, I hypothesize alternative analysis that:

- Avoid to consider access. So only compare demand and supply (alternative 1);
- Avoid to consider demand, so only highlights equitable distribution of resources (alternative 2);
- Avoid to disaggregate among ES, considering only the total ES supply (alternative 3);
- Considers population density instead of vulnerable individuals as demand, per sample area (alternative 4).

5.4 Results

5.4.1 Supply, demand and access analysis

Mapping ecosystems in the four sample areas, I found a total amount of almost 300.000 m2 of ecosystems, considering trees, grass and shrubs, and bare soil (this is between one third and one fourth of the total surface). More specifically, the sample area with the largest surface covered by green is sample area 1 (almost 100.000 m2), followed by sample area 3 (83.220 m2), sample area 4 (55523 m2) and sample area 2 (55021 m2).

However, if we consider the total amount of population in the four sample areas, the result is around 50 m2 of green per person, which is far above the standard suggested by World Health Organization (WHO) of 9m2 per person. To this concern, it is crucial to say we selected four sample areas from the most central and densely inhabited parts of the city, but sample area 1 contains a big urban park and the values of green per capita of sample area 1 increases consistently the average green per capita value. In terms of total green per person in the four sample areas, the best case is represented by sample area 1, as mentioned (118 m2 per person), followed by sample area 2 and 3 (around 34 m2 per person), and sample area 4 (19 m2 per person).

5.4.1.1 Supply

Based on the assumptions and methods outlined above, we estimated the supply of carbon storage, air pollution removal, cooling and noise reduction for the four sample area (see Figure 5.2). All scores are expressed in a scale from 0 to 10, where 10 represent the best performance possible.

The average score for carbon storage supply among the four sample areas is 2.1. More specifically, sample area 1 presents the best score (2.7), followed by sample area 3 (2.5), sample rea 4 (1.7) and sample area 2 (1.6). In this case the best score (sample area 1) compared to the lowest (sample areas 2) implies a 50% better performance, which corresponds to 0.7 Kg/m2 stored more.

For air pollution removal, the average score of supply considering the four sample areas is 1.5. More specifically, sample area 3 presents the best score (2.2), followed by sample area 1 (1.6), sample area 2 (1.4) and sample area 4 (0.9). The difference in implications if we compare scores for sample area 3 and 4, is that sample area 3 can remove double quantity of pollution compared to sample area 4 (0.6g/m2/year compared to 0.3g/m2/year).

For cooling, the average cooling supply score considering the four sample areas is 1.8. The best performance shown by sample area 3 (2.2), followed by sample area 1 (2.1), sample area 2 (1.6) and sample area 4 (1.5). The difference of cooling provided between sample area 3 and 4 is around half a Celsius degree.

For noise reduction, the average score among the four sample areas is 1.6, with the best performance shown by sample area 3 (1.9), followed by sample area 1 (1.5) and sample areas 2 and 4, both with 1.4. In this case, the difference in decibel considering the performance of the best sample area and the sample area with scares noise reduction supply is negligible (0.1 decibel).

To summarize, sample area 3 shows the best ES supply for three of the fours analyzed ES, namely: air pollution removal, cooling and noise reduction. For carbon storage, the best performance is presented by sample area 1. Considering that the total amount of green of sample area 1 is higher than the total amount of sample area 3 (100.000m2 compared to 80.000 m2 c.a.) it is evident that the typology of green is crucial when we talk about supply. In general, sample areas 1 and 3 have the best scores for ES supply, while sample area 4 the lowest, even though its green is more than the green of sample area 2.

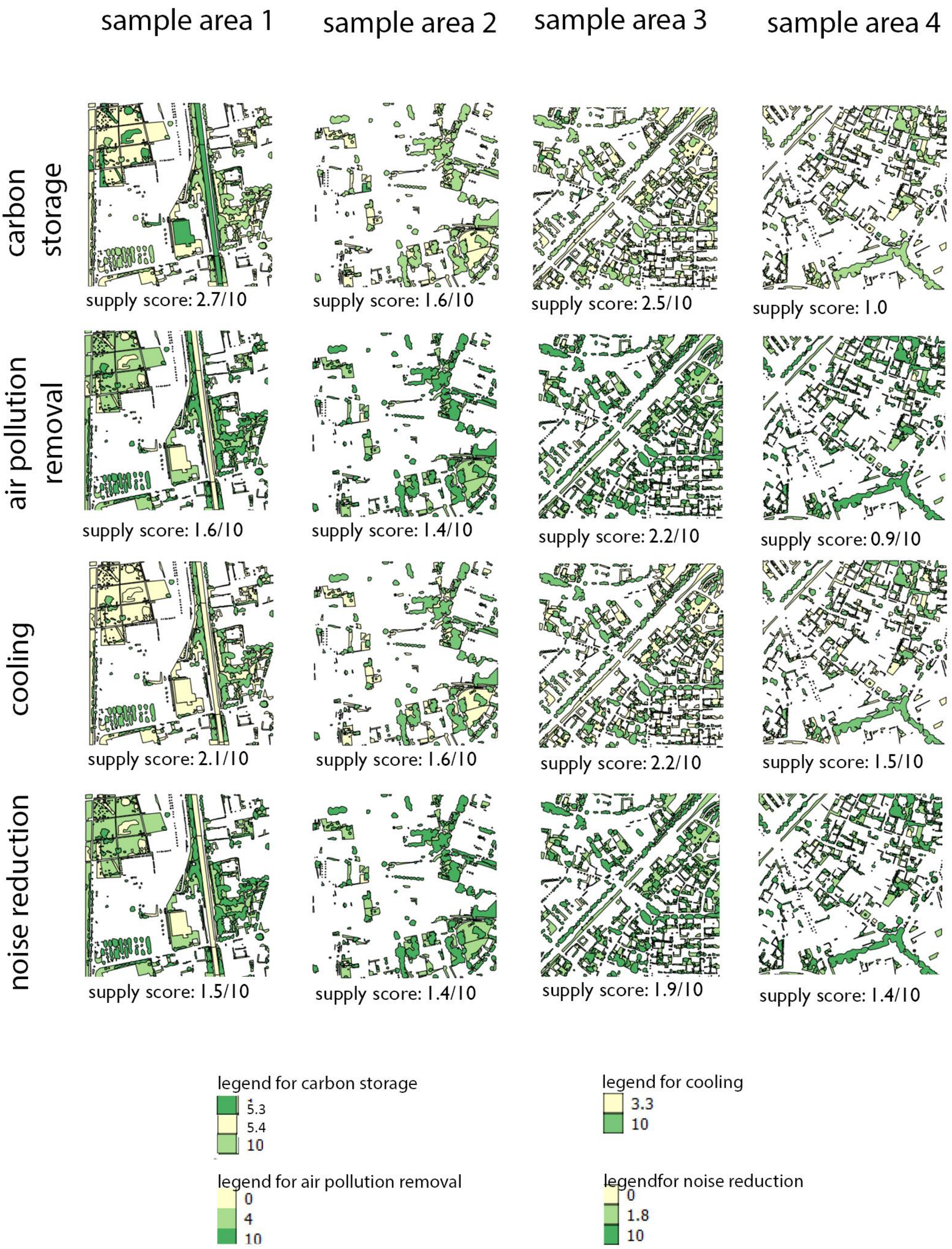

Figure 5.2 Supply analysis

5.4.1.2 Access

Results from the access analysis can be grouped into two different types of results. The distinction is due to the nature of the analyzed ES, previously distinguished between those ES depending on proximity (cooling and noise reduction) and those that don't (carbon storage and air pollution removal).

Access analysis results from the first type of ES provides an average score homogenously distributed within the sample area. For these ES, no physical or institutional barrier to access them was considered. More specifically, for carbon storage, the ES can be considered equally distributed in the whole city and as score of its performance the average sum of all green area is considered. For this reason, access to carbon storage does not differ among the four sample areas (with a score of 2.1). Similarly, air pollution removal do not depend on proximity, but can vary from neighborhood to neighborhood. For this reason, the score for air pollution removal for each sample area corresponds to the sum of all air pollution supply of ecosystems within the sample area, divided by the surface of the sample area. Results show that best access to this service is present in sample area 3 (2,2/10), followed by sample area 1 with a score of 1,6/10, sample area 2 with 1,4/10 and sample area 4 with 0,9/10.

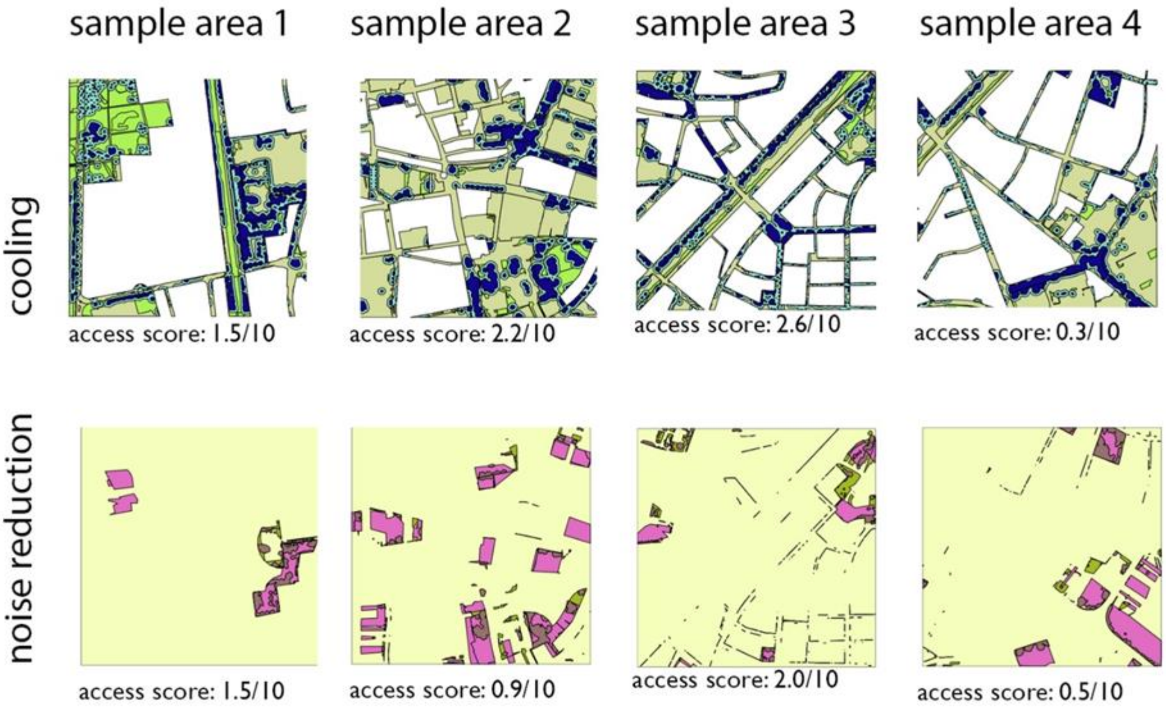

Figure 5.3 Access analysis

Access analysis results for the second type of ES, which depend on proximity and consequently are heterogeneously distributed, considers the flow of ES and only m2 of flow in non-private areas was accounted (Figure 5.3). Access to cooling is maximum in sample area 2 (3), followed by sample area 1 (2.8), sample area 3 (2.6) and access to cooling in minimum in sample area 4 (2). Access to noise reduction is maximum again in sample area 2 (0.8), followed by sample area 4 (0.5) and lastly by sample area 1 and 3, both with an access score of 0.3.

5.4.1.3 Demand

The total amount of population considering the four sample areas is of 7878 people. About 42% of these (3314) are vulnerable individuals. Concerning the distribution of population among the four sample areas, the most populated one is sample area 4, with 2942 people, followed by sample area 3 (2484 people), 2 (1604 people) and 1 (850 people). In our areas of study, the distribution of vulnerable individuals is almost proportional with the distribution of the population density, meaning that the area with the highest population density is also the area with highest amount of vulnerable individuals. Thus, vulnerable individuals in sample area 4 are 1230 people, vulnerable individuals in sample area 3 are 983, vulnerable individuals in sample area 2 are 661 and in sample area 1 are 440 individuals. In relative terms, the highest percentage of vulnerable individuals among the population is in sample area 1 (52%), followed by sample area 4 (42%), sample area 2 (41%) and sample area 3 (39%).

Coherently with supply and access analysis, to assign an overall score for demand to the four sample areas, we considered the absolute numbers of vulnerable individuals for sample area and we normalized it from 0 to 10. For this reason, the area with the highest demand is sample area 4 (score 10), followed by sample area 3 (8), sample area 2 (5) and sample area 1 (4).

5.4.2 Results for equitable distribution of ES

Given that access analysis already includes information related to the supply, we aggregated the results from the access analysis together with the results from the demand analysis to obtain an overall equity assessment.

As shown in Figure 5.4, our Equitable Distribution of ES score recognizes that the best sample area for carbon storage is sample area 1, followed by sample area 3, sample area 2 and sample area 4, relatively with scores of 0.6, 0.4, 0.3 and 0.2. The highest scores is for the best situations –where there is high access to ES and low concentration of demand. The equity score for air pollution removal is maximum for sample area 1 (0.5), followed by sample area 2 and 3 (both with an equity score of 0.3) and minimum for sample area 4, with an equity score of 0.1. The equity score for cooling is again maximum for sample area 1 (0.8), followed by sample area 2 (0.6), 3 (0.3) and 4 (0.2). The score for noise reduction sees at the best position sample area 2 (0.2), followed by sample area 1 (0.1), sample area 4 (0.1) and the worst score is for sample area 3, around 0. Figure 5.4 summarizes the equity results.

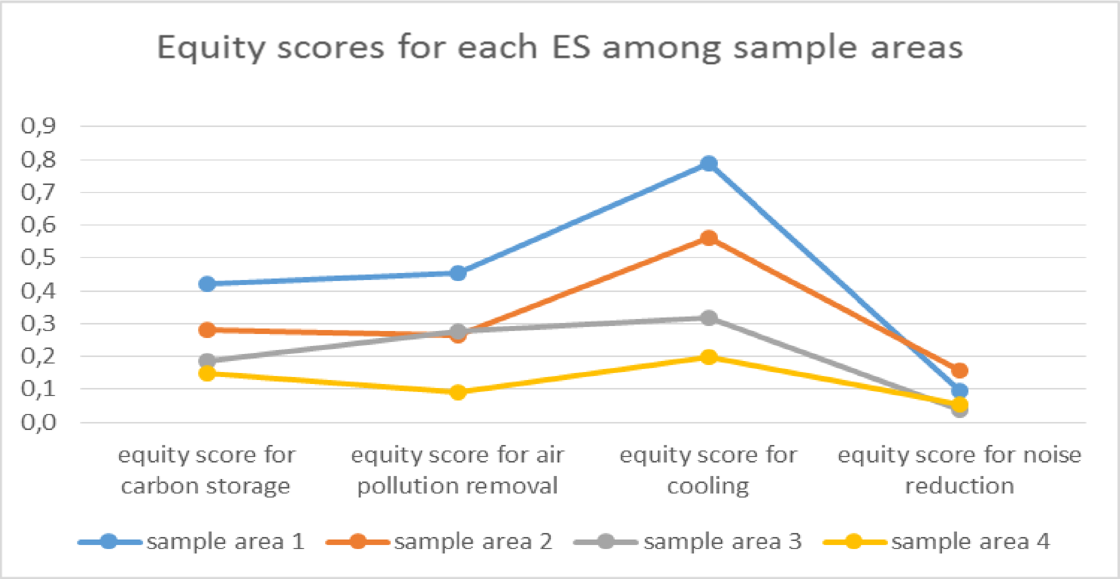

Figure 5.4 Equity scores for each ES among sample areas

By comparing such results coming from the equitable distribution of ES obtained with our analysis, with the alternative analysis listed in subsection 3.5 that do not follow all the criteria of Table 5.1, we can observe most relevant differences in results (see Figure 5.5)

By comparing our results with alternatives 1, 2, 3 and 4, we can observe that for carbon storage and cooling, alternative 4 is the one providing the most similar results to our equity assessment. Alternative 4 is the one that considers the population density instead of vulnerable individuals as demand indicator. However, this is a coincidence to the fact that in our sample areas the area with highest poplutation density is also the area with highest number of vulnerable individuals. For air pollution removal and noise reduction the alternatives that provide most similar results to our assessment's results are alternative 1 and alternative 3, that are respectively the alterternative that do not consider the access to the ES and the one that considers the average ES provisioning instead of diaggregating per ES. It is easy to understand that air pollution removal assessments does not change if we consider access or supply, since it does not depend on proximity and access becomes less relevant.

To conclude, the alternative that always provide results with the biggest difference compare to our assessment is alternative 2, telling us that if we do not consider the demand, but only the access to Es, the preferabilty of areas would be completely misleading.

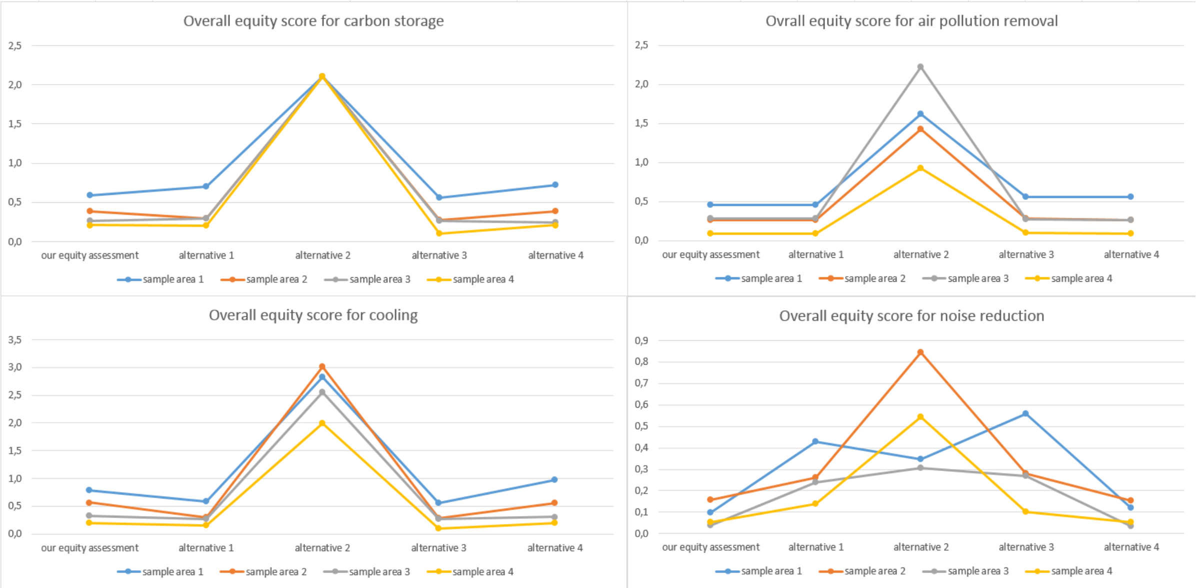

Figure 5.5 Comparisons among ES assessment alternatives

To summarize, compared to our equity assessment, avoiding to consider access (alternative 1) would have it major effects on noise reduction assessments, followed by cooling, carbon storage and the less impacted ES assessment would be the one related to air pollution removal. Avoiding to consider demand (alternative 2) would have big aberrations on all ES assessments. Avoding to consider ES separatly and using and average supply and access assessments for all of them (alternative 3) would mainly impact results for carbon storage and cooling, where we have the biggest range of different in results from the best sample area to the worst sample area. Substituting indicator for demand with popultation density instead of number of vulnerable individuals in this case would mainly affect results for air pollution removal and noise reduction, but in difference is trivial. In case the distribution of vulnerable individuals would be less parallel with distribution of population among the areas, such results would show a relevant change.

5.5 Discussion

The effectiveness of any assessment relies on the coherence between the goal that determines its design and the goal that underpins its application. In other words, if an ES assessment it is not designed to investigate distribution of ES, it will hardly provide complete and fitting information for the purpose. The lack of ES assessments intentionally conceived to support planning in pursuing equitable distribution of ES might provide misleading information, through ignoring some key elements or investigating them through too aggregate data.

Our work provides an ES assessment overtly designed to investigate equitable distribution of ES. Thus, it analyzes all three key elements of distributive equity: the supply the access and the demand. Additionally, all three elements are investigated following criteria suggested from the literature to properly address the purpose (see section 2).

The first step of our methods focuses on the choice of four sample areas. The shift from average scores for the whole city to the same scores computed for each of the sample areas already highlights existing un-equalities and provides useful information in terms of priority for action. For example, just by disaggregating the average score for the city in scores for each sample area, we discovered that the most disadvantaged area in terms of presence of green per capita is sample area 4, followed by sample area 3, sample area 2 and the best situation takes place in sample area 1.

Results show that adopting this general and unique indicator for equitable distribution of resources (m2 green per capita) might be misleading in describing equitable distribution of ES. Most disadvantaged sample areas in terms of presence of green per capita do not match with most disadvantaged areas according to our results for the equitable distribution of ES. To start with, there is not a most preferable sample areas for all situations: it depends on the ES we are interested in. For carbon storage, best situation is represented by sample area 1, but for noise reduction sample area 2 has the highest scores.

More specifically, the supply analysis highlights the importance of distinguishing among what we generally call “green”. Different types of green, or different ecosystems, provide different ES and to a different extent. To summarize, sample area 3 –that is not the area with the highest presence of green per capita- shows the best ES supply for three of the fours analyzed ES, namely: air pollution removal, cooling and noise reduction. For carbon storage, the best performance is presented by sample area 1.

What emerges for the access analysis if that this type of analysis is not equally important for all ES. For example, for ES non-depending on proximity the addition of access information to the equitable distribution of ES analysis does not change the results. On the contrary, for cooling and noise reduction, the areas with the best supply do not correspond to the areas with the best access to the ES: best cooling supply is provided by sample area 3, while best access to cooling is provided by sample area 2. Best noise reduction supply is provided by sample area 3, but best access to noise reduction takes place in sample area 2.

Results concerning the demand analysis in this study might be misleading if used to determine the relevance of demand information in the analysis of equitable distribution of ES and, more specifically, the relevance of how to capture and assess the demand. In our case, adopting population density as proxy for the demand instead of adopting the number of vulnerable individuals does not modify the results: in any case, the sample area showing highest demand is sample area 4. However, our four sample areas represent a specific case where population density and vulnerable individuals are proportionally distributed. If it would not be the case (e.g. the area with highest population density would not correspond to the area with the highest number of vulnerable individuals), the incidence of adopting population density or number of vulnerable individuals would lead to assign priority for action to different areas.

From the comparison between our equitable distribution of ES analysis and the alternative analysis that do not follow the criteria set in section 2, we can deduce two main considerations. First, that the adoption of our analysis compared to the alternatives impacts more on the analysis of equitable distribution of noise reduction and cooling, while impact less on the analysis of equitable distribution of air pollution removal and almost does not impact on the analysis of equitable distribution of carbon storage. This can be explained though the relevance of access in the analysis of such ES. In fact, access is especially important for proximal ES and alternative analysis that do not consider it in their computations alter the results. Second, if we would need to simplify our analysis and adopt one of the alternatives, the alternative providing the most similar results to our equitable distribution of ES analysis is alternative 4, which uses population density instead of number of vulnerable individuals. We already explained above in this section the reasons for this. The alternative that provides most different results compared to our analysis is alternative 2 that avoids considering the demand. Thus, if we only assess the availability of ES (in terms of supply and access) ignoring the demand, the ranking of most disadvantaged sample area would be completely different. Between these two extreme points, we have results from alternative 1 and 3, that avoid to consider access and that avoid disaggregation among ES. In the case of access, results change in particular for the cooling and noise reduction analysis. In the case of aggregated ES supply, differences impact on all ES except for carbon storage.

The work presents some limitations to be improved. First, ES access analysis in general is still in its pioneering stage and in spite of the small contribution made her, there is still need to go deeper in determining how to properly assess access to ES. Second, for the demand analysis, I adopted one unique category of vulnerable individuals. It is true that some people are more susceptible to harm more than others due to their different capacity to deal with the hazards (Kazmierczak, 2012). However, vulnerability differs from hazard to hazard. There is chance to zoom in the complexity of regulating services demand and distinguish among different groups of demand, specifically for each ES. Third, the supply analysis is based on one single indicator per ES, while the adoption of multiple indicators would lead to more detailed results.

The cited limitations are due to the present state of the knowledge for the access analysis, while also rely on a choice for the demand and supply analysis. Thus, for the demand and supply analysis we tried to adopt analysis that would become too complex, costly and time-consuming to be replicate for other contexts. As a matter of fact, the analysis of equitable distribution of ES provided by this paper, provides a synthetic overall picture about the distribution of ES (in terms of supply and access) and the need for them. Such quantitative and spatial explicit overall picture, already capture where more advantaged and less advantaged areas are in the city and represent a tool to set and identify priorities for urban planning to enhance an equitable distribution of ES in their cities.

5.6 Conclusion

Equitable distribution of resources –and more specifically of ES- is one of the structuring elements involved in the pursue of general equity. ES assessments can provide a decisive support to the investigation of the distribution of ES to better address equity in the planning practice. The ES concept, more than an objective of study or the goal of some policies, can represent a tool itself. In fact, the ES concept underpins the understanding and quantification of how ecosystems provide services and spatially define the relationship between their structure, functions, ES and the related benefits (Braat and De Groot, 2012) at the proper scale. For this reason, ES assessments represent a powerful tool for planners to design cities that are more equitable.

We borrowed, combined and adopted methods from existing ES knowledge to capture distribution of regulating ES in a city and demand for benefits coming from such ES. The entire work was driven by criteria set from the ES field and environmental equity field to assure the match between the design of the analysis –the methods- and the purpose of the analysis: provide useful information to planners to support them in pursuing equitable distribution of regulating services in cities.

There a big challenges in data availability and in the definition of the scale at which to disaggregate. Although a comprehensive consideration of ES would be ideal, data and resources limitations will ultimate with restrict number of data and information considered in the assessment (Tallis and Polasky, 2009). However, the potential of applying such a holistic approach to the investigation of distribution of ES, involving a spectrum that goes from merely biophysical issues to socio-economic considerations cannot be ignored. Even though such kind of holistic analysis, implying the use of disaggregated data and complex assessments, can be costly and time-consuming (Gomez-Baggethun and Barton, 2013), there is need to keep on walking this path and to go further. Firstly, more research is needed to better address access analysis. Secondly, more research is needed to provide more detailed demand analysis for regulating services.

Human-environment systems are complex adaptive systems and despite the numerous efforts and studies about phenomena and biophysics functioning of ecosystems and their ES provisioning, “we presently have only the beginnings of an understanding of the vulnerability and resilience of coupled human-environment systems” (Levin and Clark, 2010). No simple assessment can properly describe and capture the essential feature of such a complex picture. To pursue equitable distribution of ES the challenge is in going deeper and more detailed in the analysis of all elements, while keeping methods and results the most synthetic possible.

Chapter 6

Conclusions

The main goal of this thesis was to contribute to bridge the research field of ES with urban planning, in order to mainstream ES knowledge into practice and operationalize it in "everyday" urban planning. The work was driven by four specific objectives:

1) Providing an overview of the current state of the art related to the inclusion of Ecosystem-based measures in urban planning, identifying and discussing the main shortcomings and advancing possible solutions.

2) Developing an operative approach to estimate the cooling capacity provided by Green Urban Infrastructures to support urban planning.

3) Testing the application of ES assessments to answer real planning questions in two urban case studies.

4) Developing guidance to support equitable distribution of ES in cities.

This chapter presents and discusses the main findings of the research and draws some overall conclusions.

In response to the research questions related to the first objective, we found that the most common EbA measures included in climate adaptation plans are related to the generic creation of new green areas, which is not surprising given that the enhancement of green areas is a typical objective pursued by planners. Least frequent EbA are those related to wind circulation, most likely because the effectiveness of these measures is related to the morphology of the city. More surprising is the scarce care devoted to the design of impervious surfaces and to measures aimed at mitigating stormwater run-off thus preventing urban flooding.

By tracking the inclusion of EbA in the different components of plans, we identified in the implementation component the most frequent missing link between the acknowledgement of EbA and their actual operationalization.

In general, the results of the review show that EbA are finding their way in climate adaptation plans. However, based on our findings, we can formulate three main recommendations to

improve the inclusion of EbA in climate adaptation plans:
i) there is an evident need to enhance baseline information upon which EbA are proposed and designed, in both quantitative and quantitative terms, to better inform decision-makers about costs and benefits related to EbA. Particular attention should be paid to the assessment stock and flow of ES in and from Green Urban Infrastructure;
ii) Co-benefits triggered by EbA beyond climate adaptation need to be more explicitly taken into account;
iii) further efforts should address the interaction between climate plans and other planning instruments.

In response to the research questions raised accordingly to the second objective, results show that the components that mainly determine the cooling capacity of a GUI are: tree canopy coverage, soil cover, and size. These features do not equally affect the cooling capacity. Generally, the most important component is size, followed by tree canopy coverage and soil cover. Additionally, a GUI with a higher cooling capacity assures better performance in any climatic region. On the other hand, depending on the climatic region where it is located, the same cooling capacity score implies different air temperature reductions (e.g. a GUI with a cooling capacity score of 80 out of 100 produces around one more Celsius degree of temperature reduction in a city in the Mediterranean climate region compared to a city in the continental climate region).

The Amsterdam case study was used to validate and test the developed methodology. Furthermore, the application provided some practical insights on the effectiveness of possible planning actions addressing the different components of the cooling capacity. For example, it emerged that in the case of a small area, it is more worthwhile to increase the tree canopy coverage than to change the soil cover.

This methodology contributes to the set of ES assessment tools designed for the urban scale, addressing one of the major gaps highlighted in our review (chapter 2, objective 1). The methodology is easily applicable and, using limited input data, it provides some information that can guide planners in understanding: i) which are the physical characteristics of a GUI involved in the provision of cooling; ii) how a GUI should be designed to maximize its cooling capacity; iii) which is the state of things in the city in terms of cooling capacity provided by the existing GUI. However, to provide a complete picture, there is need to include the analysis of the flow of ES and an analysis of its beneficiaries.

In responses to the research questions deriving from the third objective, we first succeeded in applying the cooling capacity methodology to another city (Trento) with different data availability compared to Amsterdam.

For Trento, additionally to testing again the methodology, we mapped the flow of ES. The methodology was applied to help design and assess one of the strategies envisioned by the current urban plan of the city, identifying which of the potential greening interventions on the existing brownfields would maximize the provision of cooling and reach the highest number of beneficiaries.

For Addis Abeba, we applied a multiple ES assessment based on land-cover classes. We assessed five ES, namely carbon sequestration, carbon storage, run-off mitigation, local climate regulation and air pollution reduction. The average sum of the five ES was computed and results were aggregated per subcity. Similarly, we computed demand of regulating services for each subcity, considering population density and number of vulnerable individuals per subcity as proxy of eventual beneficiaries. The comparison of demand and supply allowed defining a priority ranking for intervention in the different areas.

The two applications provide evidence of the applicability of ES assessments in context with different data availability and in different climatic regions. Moreover, they were useful to show to decision-makers the utility of ES assessments to support planning decisions and interventions. In the two case studies, we started to address the issue of the flow of ES and of the demand for ES (potential beneficiaries), and to assess multiple ES with the aim of providing insights about possible trade-offs and synergies. Given the utility of these information to support urban administration to effectively include the ES concept in their planning practice, these issues were more systematically addressed in the following chapter.

The research activity built on the fourth objective tackled all research questions raised at the beginning of the thesis (chapter 1). We identified criteria to analyze ES supply, access to ES and ES demand in order to assess equitable distribution of ES. The main principles that we derived can be summarized as follow: i) ES supply analysis should identify where the variety of ES services are generated, to which extent, and what the underlying spatial structures are. ii) for an access analysis there is need to define first how the flow of each ES works and whether the benefits depend on the proximity of beneficiaries to the ES flow. If this is the case, it becomes crucial to understand scale and direction of the flow and if there are physical or institutional barriers to access such flow. iii) To consider demand for equity, it is equally crucial to identify the “who” – the ES target that expresses the demand -, and where such demand is located.

By applying the three analyses to four sample areas in the city of Trento, results show that most disadvantaged areas in terms of presence of green do not necessarily correspond with most disadvantaged areas in terms of equitable distribution of ES. Moreover, it emerged that it is not possible to identify a best performing area for all the ES at the same time. The best performing area for a specific ES, for example carbon storage, do not correspond to the best performing area of another ES, e.g. noise reduction. This finding highlights that GUI provide ES differently according to their physical characteristics and location, which raises the question of the scale and accuracy of information to provide to planners. This issue, already emerging in chapter 3, here reaches a higher relevance. Additionally, analyzing the flow of ES and the access to such flow represents an important step compared to chapter 3 and 4, and to the recommendations and needs that they raised.

Moreover, our score for equitable distribution of ES explicitly considers the demand. This point was also a major issue included in the conclusions of chapter 3 and addressed by chapter 4 but still in its early steps. The final comparison among results from different approaches to ES assessment shows the difference in terms of results between considering demand or not in the assessment.

As Stiglitz (2012) stated, wellbeing in the world is not a matter of availability but distribution of resources. This thesis started from the biophysical side of the ES concept and went through all the Cascade model (Braat and De Groot, 2012) to reach the socio-economic side where beneficiaries are represented.

There should be no effort to avoid complexity: human-environment systems are complex and they can be neither investigated nor managed through simple questions and answers. However, research can provide its contribution in looking for the right trade-off between complete and synthetic information to support planning and reducing step by step the distance between theory and practice, to build more sustainable and equitable cities, together.

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