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INTEGRATION OF NATURE-BASED SOLUTIONS IN URBAN AREAS: EXPLORING EMERGING APPROACHES

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Thesis abstract

Nature-based Solutions (NBS) have assumed an increasingly important role in urban planning. Given their relevant potential in enhancing natural capital at different scales and in providing several Ecosystem Services (ES), they are particularly relevant for climate adaptation and mitigation. By definition, they are multifunctional, as they are assumed to provide at the same time multiple benefits on environmental, social, and economic domains.

Despite the increasing fame of NBS, cities are still facing some difficulties in the identification of policies for the implementation of such solutions. Since cities include a complex set of stakeholders, it is necessary to identify flexible schemes that allow engaging them in light of their social, economic, and cultural diversity. Another relevant challenge consists in the assessment and economic valuation of the benefits generated by NBS at the urban scale. An overall and integrated assessment of all the impacts generated by NBS is necessary to fully compute the benefits related to the environmental, economic, and above all social dimensions. The NBS impact assessment is a prerequisite for the definition of policies capable of implementing NBS at the urban scale.

This research seeks to analyze and assess methodologies and policy instruments to foster the NBS implementation and management at the urban scale. Such a task requires integrating knowledge from different disciplines (urban planning, natural sciences, economic and social sciences) to include all the elements and the scales involved in NBS planning. The aim is to identify the main drivers for the implementation of NBS, taking into consideration how these infrastructures impact on the social and public value of ES in cities. For this purpose, the thesis investigates i) the assessment methodologies to measure the impacts generated by ES provided by NBS; ii) the approaches to valuate these impacts considering the social, economic, and environmental dimensions and, iii) the instruments that can be adopted to foster the implementation of NBS with a particular focus on Payment for Ecosystem Services schemes (PES).

The research relies on a triangulation of qualitative and quantitative methods. The Chapter 2 is focused on the impact assessment approaches and the third Chapter on the economic valuation methodologies applicable in cities through a systematization of several case studies detected in the literature. Chapter 4 investigates the benefits generated by NBS whit a particular focus on climate change and mitigation through a review of existing literature. Furthermore, Chapter 4 includes a comparison of the PES schemes adopted in five different cities. A specific focus on the Milanese PES scheme design and impacts have been dedicated in Chapter 5.

Results show that PES have proven to be suitable for the implementation of NBS and the engagement of different stakeholders in the sustainable management of ecosystems in the contexts analyzed. The analysis of the Milan initiative highlights the main elements that enabled the success of the PES, allowing the city government to involve different stakeholders to manage and maintain green areas. Nonetheless, it also confirms that the complexity of urban environments and the interactions between many ES require a holistic perspective to ensure the optimal distribution of benefits generated by them.

The thesis contributes to the debate on the policy instruments for the implementation of NBS at an urban scale. The analysis of the methodologies for the assessment and valuation of the NBS benefits in terms of ES emphasized the importance of adopting approaches that consider the different values generated by NBS, overcoming the sectoral approach. In addition, these approaches must carefully take into account context-specific characteristics, including broader territorial dynamics and urban societal and economic parameters.

The thesis has been realized considering the results of four scientific papers that have been already published in peer reviewed journals or have been accepted for publication[1]:

1. Croci, E., Gomez, S., Lucchitta, B., Sanchez, R. "An evaluation framework to assess multiple benefits of NBS: innovative approaches and KPIs". (2021). In Nature-based solutions for more sustainable cities – a framework approach for planning and evaluation edited by Croci, E. and Lucchitta, B. Emerald publishing.
2. Croci, E., Lucchitta, B., Penati, T. (2021). Valuing Ecosystem Services at the Urban Level: A Critical Review. Sustainability. 13(3):1129.
3. Croci, E., Lucchitta, B. "Climate Change and Urban Nature: impacts and policies at the urban level". (2021). In Planning Climate Smart Cities edited by Kwi-Gon, K. and Massamba T. The Urban Book Series, Springer Nature.
4. Croci, E., Lucchitta, B., Penati, T. The Milan "Adopt a green spot" initiative as a policy design model. Journal of Environmental Science and Policy.

[1] The papers' references have been collected and organize in a single bibliography

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0 Introduction

Abstract
This section defines and frames research problems and questions, clarifying how they are investigated throughout the thesis.

0.1 Introduction and research objectives

The importance of nature for the improvement of human well-being has been widely recognized, considering impacts generated on social, economic, and environmental dimensions (Costanza et al., 1997; Gomez-Baggethun et al., 2013; Dorst et al., 2019; Dasgupta, 2021). In this context, Nature-based Solutions (NBS) literature advocates a holistic governance approach integrating different policies and regulations to the different functions of NBS (Frantzeskaki, 2019; Xing et al., 2017). NBS are defined as *"actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits"* (IUCN, 2016). NBS are useful solutions to solve several challenges that cities are facing by providing a wide range of ecosystem services (ES). So, an overall and integrated assessment of impacts generated by NBS is necessary to fully compute the benefits related to the environmental, economic, and above all social dimensions (see Chapter 1). Benefits regard different scales, from the improvement of local neighbors to the contribution to fighting climate change at the global level. So, the NBS impact assessment and the economic valuation is a prerequisite to fully understanding the social and public value of green areas in cities and for the definition of policies instruments that can facilitate the implementation of NBS at the urban scale.

This thesis aims to analyze and assess methodologies and policy instruments to foster the implementation and management of NBS at the urban scale. Such a task requires the integration of knowledge from different disciplines (urban planning, natural sciences, economic and social sciences) to fully consider and integrate the elements and the scales interacting in NBS planning. Literature on NBS also considers this governance a challenge: successful NBS implementation requires cross-disciplinary cooperation (Hansen and Pauleit, 2014) as well as collaboration across departmental entities. This collaboration is held to be crucial, as, co-benefits are generally not integrated into the plans, and impact on addressing multiple urban challenges is likely sub-optimal (Sussams et al., 2015). For this purpose, the thesis focuses on three issues related to the implementation of NBS in urban contexts: i) the assessment methodologies to measure ecosystem services provided by NBS, ii) the approaches to valuate their social, economic, and environmental dimensions, and i) the instruments to be adopted in order to foster NBS implementation.

In the first part of thesis the issue regards impact assessment frameworks that can be adopted at the urban scale has been analyzed. The assessment of the impacts generated by NBS requires the definition of adequate monitoring systems and evaluation methodologies. Despite the wide range of benefits generated by NBS, limited attention has been paid to how to measure the benefits obtained from green space. Also, the extent to which these benefits affect citizens is not properly documented. Accordingly, the first part of this thesis seeks to identify data and indicators most suitable to analyze NBS impacts, also considering the co-benefits and trade-offs that can be triggered by them at the urban scale.

Secondly the thesis focuses on the scarce data related to the economic values associated to these impacts. In fact, the economic valuation is key to reveal the “hidden values” generated through ES and so to support effective and efficient instruments to internalize the positive externalities generated (Dasgupta, 2021). Different methodologies can be applied to provide a value of benefits considering the multi-functionality of ES. This can facilitate the definition and introduction of policies instruments to protect and enhance ES through the implementation of NBS. It is important to note that currently the economic valuation still presents shortcomings in revealing the full value of ES, ordinary leading to an underestimation. The valuation of the environmental goods and services would make it easier for their inclusion in economic choices and public decision-making processes and for the design and adoption of instruments that are able to capture the value generated.

The last part of the thesis focuses on the policy instruments that can be adopted at the urban scale for the implementation of NBS, with particular attention to Payment for Ecosystem Services (PES). At this purpose, five case studies of PES schemes implementation within cities are considered and compared to identify the impacts provided and the ability to capture the value generated. The analysis compares schemes that differ in terms of i) form, ii) ecosystem services considered, iii) stakeholders involved and in particular regarding iv) the role of the public administration and the voluntary or mandatory character of the agreement. For what concerns the case study, an in-depth analysis has been performed to investigate the structure and the impact generated by the “Adopt a green spot” initiative promoted by the Milan Municipality. The Municipality designed the PES scheme to include a variety of stakeholders by defining two typologies of voluntary agreements – sponsorship and collaboration - providing flexibility in the execution of their commitments. The initiative can be interpreted as a PES, where the Municipality is the owner of the natural resource providing ES, while citizens and other stakeholders are the beneficiaries of the services provided by the green areas. The analysis aims to understand the impacts of the initiative identifying the successful elements of the policy model proposed by Milan and to investigate its strengths and weaknesses. The “Adopt a green spot” initiative was selected for several reasons. Firstly, Milan municipality systematized an initiative promoted by a local association through a bottom-up approach. Secondly, the PES scheme proposed by the city of Milan allows to "adopt" different types of urban green areas (see Chapter 5) within the city, while other PES such as the one designed by New York Municipality (see Chapter 4), or Mexico City (see Chapter 4) do not allow to select the typology of green spot to finance. Furthermore, the scheme adopted is based on two voluntary agreements that the various stakeholders decide to sign with the municipality to manage the urban green spaces. The provision of two different types of agreements can meet the needs of several stakeholders (citizens, NGOs, companies, etc.). It should be emphasized that the "Adopt a green spot" scheme has been adopted in several Italian cities. Milan was the first to implement it (the PES has been active since 2005, as described in chapter 5), which allows for a quantity of data necessary to evaluate the impact generated regarding i) stakeholder engagement, ii) areas localization, and iii) generated revenues. In addition, this also made it possible to assess its evolution over time. The case study allows to highlight the main successful factors for the design and implementation of a PES scheme in the Milanese context.

0.2 Methodological approach and thesis structure

The methodologies applied to analyze the topics mentioned above are different and are based on an inductive approach. For the analysis of NBS impact assessment indicators, the approach used is based on the systematic review of the literature to capture the diversity of findings from the rapid proliferation of NBS impact assessment studies in recent years. The literature was analyzed to identify i) the impacts generated by the different NBS on an urban scale (positive and negative); ii) the various existing indicators that make it possible to measure the ES generated by NBS; iii) the scale of the impact generated (urban, neighborhood, etc.). Findings have been synthetized, analyzed, and interpreted.

The analysis of the NBS economic evaluation methodologies is also based on the analysis of the existing literature. The methodology is composed by the following steps: i) literature review of case studies on ES valuation at the urban level, ii) analysis of the methodologies adopted in literature (description, pros, and cons), and iii) definition of a framework linking valuation methodologies with ES at the urban level. More in detail, the methodologies have been analyzed and described considering three main elements: i) the description of the methodology, ii) the ES valued through each methodology, iii) the pros and cons of the use of a methodology concerning specific ES categories. The third step capitalizes on the previous ones: pros and cons have been defined by considering the intrinsic properties of the valuation methodologies, the outcome of case studies on the valuation of ES, and the drivers that affect the implementation of such methodologies during the valuation process. This allows defining a correlation between the different assessment methodologies and ecosystem services on an urban scale.

Finally, the thesis investigates the impacts generated by the adoption of PES at the urban scale for the implementation of NBS. The selected cases were analyzed based on the following elements that characterize the PES schemes: i) ES buyers; ii) ES sellers; iii) the payment defined for the provision of the ES; and iv) the benefits generated by the ES. An exploratory data analysis method based on a set of indicators and GIS analysis was used for the analysis of the Milan case study "Adopt a green spot". The overall impacts generated by the adoption of the PES scheme are analyzed through the observation of several indicators: i) the number of contracts signed (in total and per typology), ii) the typologies of stakeholders engaged in the initiative, iii) the typology of agreement selected by different stakeholders' categories, iv) the revenues generated, and v) the investments made per meter square. The indicators aim to assess the performance of the PES. Indicators have been selected based on the peculiarities of the scheme: capacity to involve buyers and sellers of ES (number of contracts signed), capacity to generate revenues for the enhancement and maintenance of ES (revenues generated and investments made per m^2), and capacity to involve different stakeholders (typologies of stakeholders engaged in the initiative and typology of agreement selected by different stakeholders). These indicators have also been analyzed through a spatial analysis to investigate whether the value of the indicators varies based on the areas of the city considered. The hypothesis investigated using spatial analysis is the correlation between PES scheme impacts and the localization of the green areas.

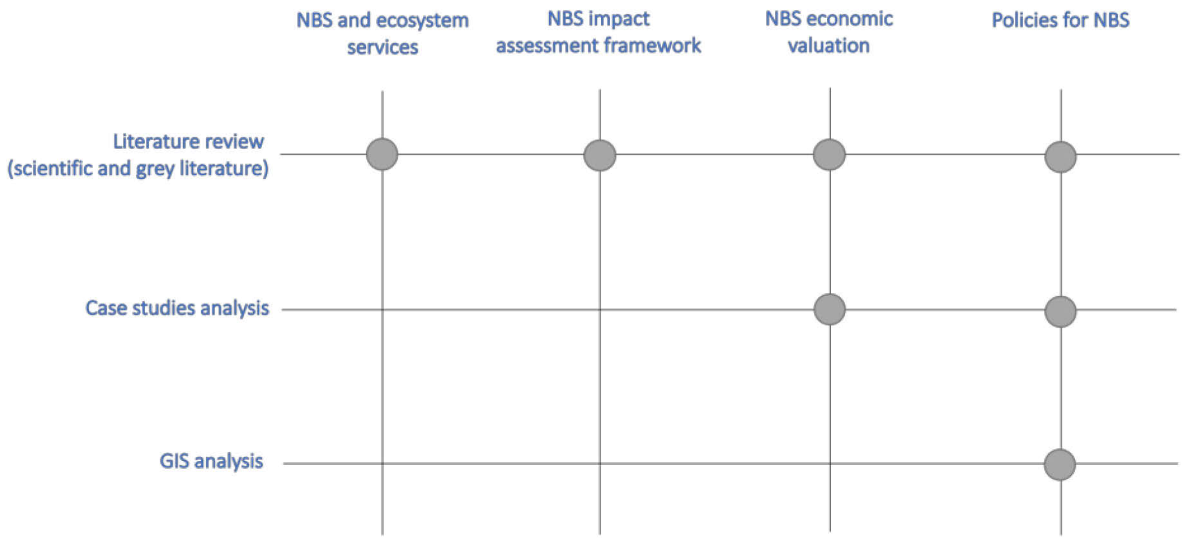


Figure 1: Main methodologies approaches adopted for the analysis development

Figure 1 summarizes the methodologies adopted for the thesis development. In the thesis conclusive chapter – section "limits of the adopted approach" – the limitations and shortcomings of the methodologies adopted are explained and highlighted.

The thesis is structured in six Chapters. The first Chapter, focused on the theoretical background, aims to introduce the subject and the state of the art. The second Chapter is dedicated to the analysis of the possible approaches for the measurement of the benefits generated by NBS (and ES provided by them) at the urban scale. The third Chapter is focused on the economic valuation of NBS benefits to investigate how it is possible to value and consider the hidden values provided by nature at the urban scale. The fourth and fifth Chapters are dedicated to the analysis of the instruments for the implementation and protection of NBS at the urban scale to i) highlight which are their strengths and weaknesses and ii) investigate if and how they are able to catch the value provided by nature at the urban scale. The final part includes the main results emerged from the analysis, the contribution to research advancement, the limits and the future research linked to the topic.

1 Theoretical background

Abstract
The introductory chapter provides a brief overview of the topic status of the art. The introduction considers i) the impacts generated by NBS and the relation with the ecosystem services; ii) the impact assessment and valuation methodologies; and iii) the policy instruments for NBS implementation at the urban scale.

1.1 NBS, ecosystem services and multifunctionality at the urban scale

1.1.1 Natural capital and ecosystem services

In the last decades growing urbanization has increased the pressure on natural resources, generating several impacts on the ecosystems and on the services provided by them at local, regional, national, and global scales (Grimm et al., 2008; Seto et al., 2012). The Millennium Ecosystem Assessment (MA, 2005) individuates land use change as one of the major causes of the loss of natural capital. Costanza (Costanza et al., 2014) assessed that the loss of world ecosystems due to land-use changes from 1997 to 2011 amounts to USD 20 trillion per year. The OECD estimates that the volume of developed land in recent years grew mostly outside the urban core while density patterns remained unchanged inside cities (OECD, 2016). Thus, urban sprawl is a major concern for many Countries and cities and its negative impact on economic, environmental, and social aspects is growing (UN HABITAT, 2016). On a larger scale, this reduces biodiversity and land for agriculture and at the same time increases greenhouse gas emissions and air pollution.

This phenomenon is exacerbated by the impacts of climate change, posing significant risks to human health, and increasing vulnerability to natural disaster risks. This brings about several challenges and issues to be dealt with in the years to come like: unsustainable consumption and production patterns, loss of biodiversity, pressure on ecosystems, pollution, natural and man-made disasters (Scalenghe and Marsan, 2009; Fann et al., 2016). Most of the flood damage that struck England in 2007 was recorded in urban areas with poor draining surfaces (Pitt, 2008). An important increase in mortality due to the association of heat waves with the "heat island" phenomenon, caused by rising temperatures and impermeable surfaces, has been observed in recent years in 15 European cities (Baccini et al., 2008; Gábor and Jombach, 2009).

The rapid degradation monitored in the state of ecosystems requires not only a better understanding of how to maintain their functions but above all, that this knowledge is recognized in a broad institutional and governance context using a multi-disciplinary approach (TEEB, 2011). In fact, local governments have the power to trigger mechanisms of change to compensate and reduce the impact of urbanization and of human activities on the surrounding environment (Folke et al. 2004). Indeed national, regional, and local authorities can improve integrated spatial planning and coordinated management between sectors to reduce the pressures from land conversion, mitigate and adapt to climate change and to ensure that green systems and biodiversity enhancement become an integral part of spatial and territorial planning (EEA, 2019). In fact, functioning ecosystems allow cities to build adaptive capacities and cope with several urban challenges such as increased risk of heat waves, floods, water supply, health, safety, and social inclusion.

Several Countries are already working on policies and actions in this field. For example, China aims to plant trees over an area up to four times the size of the United Kingdom. California is allowing forest owners to sell carbon credits to CO_2-emitting companies under its cap-and-trade scheme, and other US states are considering similar programs, which could motivate projects that establish new forests and protect existing ones (Popkin, 2019). Also, at the urban level natural capital has a huge potential in the mitigation and adaptation to climate change. In fact, through the enhancement of the natural areas in cities it is possible to absorb pollutants, regulate the temperature attenuating the heat island effect, decreasing energy consumptions in buildings and reduce flooding risks (EEA, 2019). Furthermore, this will lead to a better quality of life and well-being improvement through nature (Gomez-Baggethun et al., 2013).

Natural capital and ecosystem services (ES) have gained more and more attention at the international and local level to cope with the major challenges that national and subnational governments are facing nowadays since nature can be used to provide effective solutions deploying the properties of natural ecosystems (MA, 2005; TEEB, 2010; EC, 2013). In fact, natural capital is defined as the world's stocks of natural assets, which include geology, soil, air, water, and all living things. It is from natural capital that humans derive a wide range of services, often called ecosystem services, which make human life possible (Natural Capital Coalition, 2012). Ecosystem services are "the direct and indirect contributions of ecosystems to human wellbeing" (TEEB 2010). Several classifications of ecosystem services exist including those presented by the Millennium Ecosystem Assessment (MA 2005), TEEB (TEEB 2010) and the Common International Classification of Ecosystem Services (CICES 2013). The MA individuates four categories of ecosystem services: i) regulating (benefits obtained from the regulation of ecosystem processes, including, for example, the regulation of climate, water, and some human diseases); ii) provisioning (products obtained from ecosystems; may include food, freshwater, timber, fibers, medicinal plants); iii) cultural (non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience, including, e.g. knowledge systems, social relations, and aesthetic values); iv) supporting (services that are necessary for the maintenance of all other ecosystem services).

Starting from Costanza's work on the value of ecosystems worldwide (Costanza, 1997), a growing number of studies have proposed methods and applications for the assessment of the impacts and values generated by healthy ecosystems. In the last decade, a growing consensus has emerged on the importance of ecosystem services and their integration in the management of natural resources and territorial planning (Daily et al., 2009; Tratalos et al., 2007; de Groot et al., 2010). In fact, Countries implementing policies and actions to enhance ecosystem services are generally more resilient and less vulnerable to extreme natural events. The resilience of a system is defined as the ability to suffer a shock (Walker et al., 2004), maintaining its own functions and characteristics and recovering the initial conditions. External shocks such as floods, landslides, droughts, heat waves can cause negative consequences to social, economic, and environmental systems. The natural capital of an area performs an "insurance" function towards the impacts of changes underway, including climate change (Green et al., 2016).

1.1.2 The concept of NBS

The concept of Nature-based Solutions (NBS) has been used in different contexts. Following the definition given by the International Union for the Conservation of Nature (IUCN) in 2016, NBS are *"actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well- being and biodiversity benefits"*. The definition refers to the ability of natural resources to generate ES that ensure human well-being allowing to cope with various social, environmental, and economic challenges.

The concept of NBS first entered the scientific literature in the early 2000s, to integrate the principles of ecological theory and to improve the sustainability of food production (Blesh and Barrett, 2006). In the same years the idea of NBS began to appear in contexts such as land use management and water management - for example for the use of wetlands for wastewater treatment (Guo et al., 2000; Kayser and Kunst, 2002). Since the mid-2000s, the concept also appears in the industrial design sector in association with the biomimicry approach (Singh et al., 2007). In 2009, the term has also come into use in the literature focused on approaches and methodologies to increase resilience to the impacts of climate change in urban and extra-urban contexts, often associated with the synonym of *"ecosystem-based adaptation"* (Marton-Lefevre, 2012; van Wessenbeeck, 2014).

The role of NBS has been widely promoted by various international initiatives. Starting from the IUCN (IUCN, 2012), the concept of NBS has been used to indicate innovative solutions aimed to strength natural processes to increase social, economic, and environmental sustainability. The World Economic Forum (WEF) highlighted the potential of NBS to support innovation in the tourism sector and to enhance the cultural resources of different countries (Marton-Lefevre and Borges, 2012). The concept of NBS and the potential of natural resources in addressing the various challenges related to climate is also underlined in the Paris Agreement, the 2030 Agenda and the Sustainable Development Goals (SDG) and the Urban Agenda developed by UN-Habitat in 2016.

NBS has also emerged as a priority area for the European Union research programs. The European Commission (EC) also gives a definition to the concept of NBS, although more than one definition can be found in the related literature. For example, the Advisory Group Report for H2020's Societal Challenge (EC, 2014) talks about NBS in the context of the use of biomimicry to position the EU as a world leader in the development of technological solutions *"inspired by, using, copying from or assisted by nature".* The document underlines how NBS can contribute to building more resilient societies both in economic, social, and environmental aspects with particular reference to urban areas. Finally, in 2015, a more complete definition of the concept of NBS was given, which are described as *"solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions"* (EC, 2015).

Although it is not clear how NBS can be distinguished from other concepts associated with the opportunities to improve human well-being through solutions aimed to enhance and reinforce the action of nature. Several concepts that overlap with the definition of NBS can be found in literature. The most common are green and blue infrastructures, ecosystem-based adaptation, and ecosystem-based disaster risk reduction. Since the introduction of the term there have been several attempts to overcome these overlapping highlighting the need to create a clear link between the different concepts that refer to "natural solutions". For example, according to Balian et al. (2014), NBS can be used to build adequate green and blue infrastructure, but green infrastructure can also be part of a (larger) NBS. Potschin et al. (2016) instead suggested to consider the concept of NBS as a generic concept for all applications related to ecosystem services, natural capital and *"lessons from nature"*. Several authors have proposed to interpret the term as an umbrella concept for biodiversity and ecosystem management (Cohen-Shacham et al., 2016). Raymond et al. (2017) state that NBS is a generic term for a wide range of strategies that use natural ecosystems to address societal challenges and that green infrastructures are a type of NBS. Pauleit et al. (2017), analyzed the relationships between these concepts concluding that they are interconnected on the basis of a series of characteristics (multifunctionality, impacts generated, participation, etc.) although differences in implementation and planning methods can be observed. Finally, the authors state that the concept of NBS also includes the concepts of green and blue infrastructure, ecosystem-based adaptation, and ecosystem disaster risk reduction.

The Institute for European Environmental Policies (IEEP) and the UN Environment Program World Conservation Monitoring Center (UNEP-WCMC) defined NBS as *"actions that conserve, manage or restore nature to support biodiversity to help address societal challenges, empower people and provide job and business opportunities can be powerful tools for fighting biodiversity loss and supporting climate change mitigation and / or adaptation and disaster risk reduction while delivering further benefits to human well-being (eg health). NBS are based on the principle that ecosystems in healthy condition deliver multiple benefits and services for human well-being and can thereby address economic, social, and environmental goals simultaneously. Depending on their context, NBS are also framed as Ecosystem-based Adaptation (EbA), Green Infrastructure (GI), Ecosystem-based Disaster Risk Reduction (EcoDRR), or Natural Water Retention Measures (NWRM)"* (IEEP, 2020).

Among the different definitions of NBS there are several common elements. Firstly, NBS are actions that use natural resources to cope with various challenges such as climate change, the loss of biodiversity, the management of water resources and the reduction of risk linked to extreme events. Another important element is the NBS capacity to strength the provision of the ecosystem services. This determines the ability of NBS to cope with what are identified as social challenges or the improvement of quality of life and well-being. Finally, NBS can generate new jobs and opportunities for the development of new businesses. This leads to the last distinctive feature of NBS, the multidisciplinary that is underlined - even if not explicitly - in all definitions. In fact, NBS are multidisciplinary since they can generate multiple benefits simultaneously.

The multifunctionality of NBS is related to their natural features, which sets them apart from more traditional “grey” urban planning interventions. In some instances, ecosystem services are regarded to be a foundational concept of NBS, signaling how nature provides benefits to society (Eggermont et al., 2015; Pontee et al., 2016; Potschin et al., 2016). The concept of ES is of fundamental importance to understand the potential of NBS in providing a wide range of benefits in cities. In fact, the ecosystem services concept was developed to integrate ecological principles into economic decision-making (Pauleit et al., 2017; Wamsler, 2015). Chong (2014) states that there is a “*trend towards commoditization in relation to ecosystems and the services they deliver, where interdependencies between nature and society are interpreted from a rather utilitarian and anthropocentric perspective*”. The multifunctionality of NBS requires the introduction of a monitoring system that is able to measure the impacts generated by the NBS urban scale and that allows taking into account the various dimensions (environmental, economic and social) on which the NBS generate an impact and to manage and reduce the generation of trade-offs. The framework based on ecosystem services approach allows to consider these three dimensions simultaneously.

1.1.3 NBS and ecosystem services at the urban scale

NBS operationalize the ecosystem services approach within spatial planning policies and practices, to fully integrate the ecological dimension and, at the same time, to address current social challenges in cities. To better understand the impacts generated by NBS at the urban level and how they interact with each other, it is necessary to investigate what are the benefits that ecosystems can provide. Furthermore, given the multifunctionality character of NBS it is necessary to identify a framework for the assessment of the different impacts generated by NBS at the urban scale. The adoption of an assessment framework can allow also to individuate and mitigate the trade-off and side effects generated by NBS. At this purpose a framework based on the ES approach is quite functional.

Based on the Common International Classification of Ecosystem Services (CICES[2]) framework, a comprehensive list of ES based on NBS in urban areas is offered by Somarakis et al. (Somarakis et al., 2019):

- provisioning services: fisheries and aquaculture, water for drinking, raw (biotic) materials, water for non-drinking purposes, raw materials for energy;
- regulating and maintenance services: carbon sequestration, local climate regulation, water purification, air quality regulation, erosion prevention, flood protection, maintaining populations and habitats, soil formation and composition, pest and disease control;
- cultural services: nature-based recreation, intellectual and aesthetic appreciation, spiritual and symbolic appreciation.

The MA (2005) includes the “supporting services” section, that in CICES is mostly integrated in “maintenance services”, and in TEEB (2010) is mostly integrated in “habitat services”. In some cases, the ecological process reported as “supporting” may be intermediate and thus not separately listed as final ecosystem services. NBS represent the ecological assets that in the urban context can provide ES, meant as complex processes made possible through the existence of natural and semi-natural systems at various scales. From the classification reported, it can be seen how ecosystem services are able to generate impacts on various sectors that are fundamental for the development of life on earth and anthropogenic activities.

Nowadays a vast literature on NBS and ES is available. For example, when considering NBS in relation to ES it is possible to focus on the maintenance, enhancement, and restoration of biodiversity (Kabisch et al., 2016) or on their capacity to resource shortages (e.g., water), flood and heat risks and ecosystem

[2] https://cices.eu/

degradation caused by processes of urbanization and climate change (Dorst et al., 2019). The classification of urban ES has been deeply investigated (De Groot, 1992; Costanza et al., 1997; Bolund and Hunhammar 1999; TEEB 2011; Gómez-Baggethun et al. 2013, Gómez-Baggethun and Barton 2013; Sieber and Pons 2015). Examples of important urban ecosystem services include: i) the reduction of local air pollution (Gomez-Baggethun et al., 2013); ii) the microclimatic regulation such as reduction of the heat island effect and local climate mitigation (Schwarz et al., 2011; Colaninno and Morello, 2019); iii) the direct health benefits, such as a lower prevalence of asthma in early childhood (Lovasi et al 2008) and general health improvements (Maas et al 2006; Mitchell and Popham, 2008; Andreucci et al., 2019); iv) the reduction of the risk of floods (Danielsen et al., 2005; Costanza et al., 2006); and v) the quality of life improvement (Chiesura, 2004; Barthel et al., 2010).

Several studies analyzed the impacts generated by ecosystem services at the urban level to classify them. The first attempt was made by Bolund and Hunhammar (1999). The authors, capitalizing on the 17 groups of services identified by Costanza et al. (1997), identified six main ES at the urban scale: air filtration, microclimate regulation, noise reduction, rainwater filtration (water regulation), wastewater treatment (waste treatment), and recreational. Subsequently, in 2011 also the TEEB initiative analyzes the services performed by ecosystems on an urban scale. In total 17 services have been identified but without assessing their level of importance. The work carried out by Gómez-Baggethun and Barton (2013) is fundamental since it analyzed and systematized the ecosystem services assessed in several case studies worldwide. In total 11 ecosystem services have been identified. Subsequently, the work carried out have been updated through a further publication (Gómez-Baggethun et al., 2013) through which 13 fundamental ecosystem services at urban level are identified. Finally, in 2016 the EC publishes the MAES Urban analyzing the ecosystem services performed by natural systems at the urban level. The classification was carried out following the framework identified by CICES, considering nine different typologies of ES (Maes et al., 2016). The table 1 summarizes the ES identified.

	Bolund e Hunhammar, 1999	**TEEB, 2011**	**Gómez-Baggethun et al., 2013**	**MAES Urban, 2016**
Provisioning		Water	Food provisioning	Food production
		Food		
		Raw materials		
		Medicine		
Regulation	Water purification	Local climate and air quality regulation	Air purification	Air quality regulation

	Microclimate regulation	CO_2 sequestration and storage	Global climate regulation	Climate regulation - CO_2 reduction
	Noise reduction		Noise reduction	Noise mitigation
	Waste-water treatment	Waste-water treatment	Waste-water treatment	
	Rainwater filtration		Run-off mitigation	Water cycle and run-off mitigation
		Pollination	Pollination	Pollination
		Extreme events mitigation	Extreme events mitigation	
		Biological control		
		Soil erosion		
			Temperature regulation	Temperature regulation
Cultural	Recreation/cultural	Recreation, physical and mental health	Recreation	Recreation
		Aesthetic appreciation and inspiration for art, culture, and design	Aesthetic benefits	
		Spirituality and sense of place	Cognitive support	Education
		Tourism	Cognitive benefits	

Table 1: Ecosystem service provided at the urban scale

Based on this it can be said that functioning ecosystems provide flexibility to build capacity to adapt and to cope with different urban challenges. In fact, there are different ways to classify NBS as providers of ES to society. A first way concerns the levels of intervention and primary objective of NBS, as explained by Eggermont et al. (2015); a second way, presented by Raymond et al. (2017) and further developed by Dumitru and Wendling (2021), considers the societal challenges addressed by NBS; a third way focuses on scale - as highlighted by Somarakis et al. (2019). Raymond et al. (2017) - presents an impact evaluation framework for NBS across ten identified challenge areas related to climate resilience in urban areas. Dumitru and Wendling (2021) expand the challenge areas to 12: Climate Resilience, Water Management, Natural and Climate Hazards, Green Space Management, Biodiversity Enhancement, Air Quality, Place Regeneration, Knowledge and Social Capacity Building for Sustainable Urban Transformation, Participatory Planning and Governance, Social Justice and Social Cohesion, Health and Wellbeing, New economic opportunities, and green jobs. Most of these challenges are directly linked to the ecological process and ES provided by NBS and some of them (Knowledge and Social Capacity

Building for Sustainable Urban Transformation, Social Justice and Social Cohesion, New economic opportunities, and green jobs) are linked to social and economic co-benefits the NBS can provide. In these cases, a relationship with NBS is not direct, although undoubtedly exists (Ipbes, 2015; Raymond, et al., 2016; van Den Berg et al., 2017).

An assessment framework based on ecosystem services can also identify the interaction between these impacts to analyze possible trade-offs on an urban scale. However, it can be said that in the literature there is a lack of data on the evaluation of the negative impacts of NBS and above all there is also a lack of an evaluation methodology that is able to consider the synergies and trade-offs that are created between different functions of the NBS. A correct assessment of the impacts generated is functional to the definition of policies instruments to foster the implementation of NBS at the urban scale.

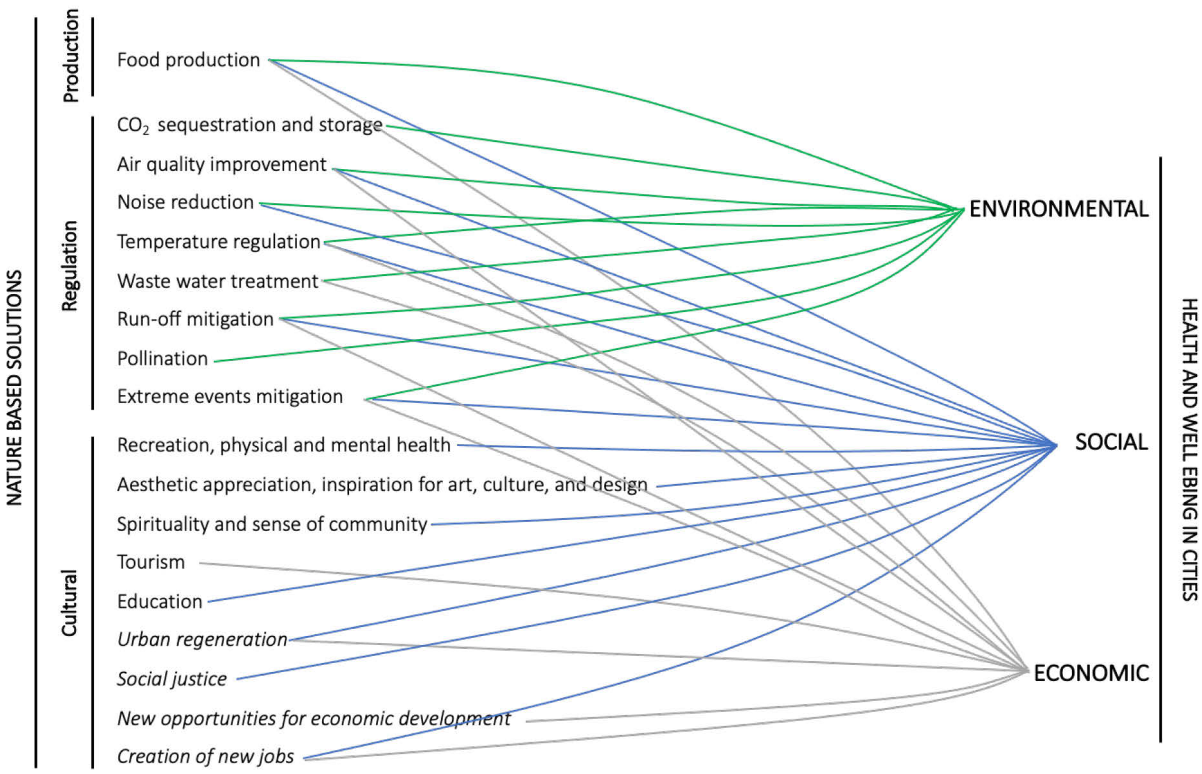


Figure 2: NBS and ecosystem services production and impacts on environmental, economic, and social dimensions (elaboration based on the literature review)

1.2 The impact assessment and economic valuation of NBS benefits

1.2.1 NBS impact assessment: ecosystem disservices, synergies, and trade-offs

The different typology of impacts generated by NBS on an urban scale implies defining adequate monitoring and measurement systems. Up to now, different sets of indicators have been proposed for

NBS impacts assessment, but on an urban scale, several problems have still been identified in their systematization and application. One of these is precisely the multifunctionality of NBS. NBS are implemented with a particular purpose - e.g., climate change mitigation - and consequently, in many cases, the measured impacts are strictly related to it. In fact, there is a lack of practical, and targeted guidance for the processes that enable the consideration and assessment of co-benefits within and across the stages of implementation and decision-making (Raymond et al., 2017; Ürge-Vorsatz et al., 2014). The assessment of NBS impacts is in many cases restricted to single challenge areas (e.g., environmental) and rarely addressed cross-sectoral impacts (e.g., between environmental and social effects, or environmental and economic) (Bell, 2012; Urge-Vorsatz et al., 2014; Spencer et al., 2017; Bouwma et al., 2017; Raymond et al., 2017). Moreover, there is also a lack of an evaluation methodology that is able to take into account the synergies and trade-offs that are created between different functions of the NBS (Hegetschweiler et al., 2017; Mexia et al., 2018). Identification of synergies and trade-offs between different impacts is required, to understand which characteristics of nature-based solutions can act as enablers or amplifiers of effects, and which might act as buffers of negative trade-offs, thus increasing the potential for multi-functionality and innovation.

Besides NBS benefits at the urban scale, the ES can also generate negative impacts if NBS and if not well planned they can also generate trade-off. In literature, the main negative impacts related to the implementation of NBS in urban contexts have been highlighted. ES negative impacts are classified as "ecosystem disservices". Ecosystem disservices are defined as “ecosystem functions that are perceived as negative for human well-being” (Lyytimäki and Sipilä 2009; Shackleton et al., 2016; Vaz et al., 2017). These are closely related to physical and chemical processes. In fact, inefficiencies range from problems related to air quality with respect to certain types of plants (e.g., pollination), to damage caused to infrastructures, to obstruction or reduction of air or light circulation up to arrive at possible damage caused by the presence of free animals. These ecosystem "disservices" must be considered in the planning of NBS to assess the potential negative effects at the urban level (Gómez-Baggethun & Barton, 2013).

For example, NBS can decrease air pollution, which can generate a decrease in diseases related to air pollution, and as a secondary impact decrease the expenditure on the public health service. It is possible that through the increase of trees in urban areas the amount of CO_2 sequestered increases and that the heat island effect decreases, but at the same time, the concentration of trees can cause emissions of biogenic volatile organic compounds - VOCs - (Livesley et al., 2016) and create allergic reactions (Carianos et al., 2019). Therefore, a thorough analysis according to each local context is needed to select the right species, as well as the spatial arrangement and management procedures. Another example is the increase in biodiversity and vegetation in some areas of the city. Some studies show that increasing the biodiversity of green spaces increases the attractiveness of the areas and the well-being of visitors (Carrus et al., 2015; Sang and Ode Sang, 2015). At the same time, dense areas of vegetation can generate feelings of lack of security, and therefore limit their use (Peschardt and Stigsdotter, 2013; Maruthaveeran and Konijnendijk van den Bosch 2014). Therefore, while areas of dense vegetation could have positive environmental effects, they could have a reduced health impact, leading to avoidance of their use (Nordh et al., 2009; Hegetschweiler et al., 2017). Furthermore, some NBS such as trees can damage grey infrastructure during extreme weather events (e.g., storms). Private property and utility service damage are common challenges in urban forestry, and there is the need to assess and manage these risks to mitigate disservices (Klein et al. 2019; Roman et al., 2020). Trees' can generate disservices also on transportation and sewerage, in fact they can obstruct vehicular traffic and pedestrians on roads and sidewalks, and their roots may block sewer pipes (Roman at al., 2020).

However, evidence about provisioning patterns of ecosystem services and disservices at the urban scale is still needed (Pauleit et al., 2005; Tratalos et al., 2007; Barbosa et al., 2007; Lyytimäki et al., 2009). In particular, there is also little known about interactions between ecosystem services in urban areas (Nelson et al., 2009; Raudsepp-Hearne et al., 2010; Ruijs et al., 2013; Schulp et al., 2012). Planning NBS at the urban scale can be quite challenging given the possible disservices that can emerge from NBS and interaction between the different ES should be considered when planning NBS at the urban scale. NBS, by definition are multifunctional, and generate a wide range of ES. Challenges in developing and managing multifunctional urban spaces can emerge. In fact, different types of interactions between ES can occur, these interactions are defined as synergies or trade-offs. A synergy is a positive correlation between two ES. A Trade-off "occurs when one service is enhanced at the expense of another" (Raudsepp-Hearne et al., 2010). Synergies and trade-offs are triggered by a management choice (Verhagen et al., 2018) or human intervention (Deng et al., 2016). Analysis of the synergies and trade-offs may support decision making and policy instrument design at different administrative and governing levels from, for example, local municipal scale (Verhagen et al., 2018). In literature, some analysis of the synergies and trade-offs that can occur at the urban scale are emerging. Some trade-offs have been identified:

1. Howe et al. (2014), Dobbs et al. (2014) and Sylla et al. (2020) found that increasing provision services can decrease regulating services (e.g., the increase grain production can and capacity of ecosystems to mitigate nitrogen leaching and the water conservation) (Baró et al., 2017, Haase et al., 2012).

2. Provisioning and cultural services showed also negative correlation (Dobbs et al., 2014; Sylla et al., 2020; Pena et al., 2018; Hermes et al., 2018; Sun et al., 2017; Yang et al., 2015) (e.g. timber production can compromise aesthetic value of landscapes: the presence of forest plantations are perceived as detrimental to the landscape as they cause homogeneity in it; or intensive large farm agricultural production areas ensure high food provision, but reduce the naturalness of the landscape and its diversity).
3. Dobbs et al. (2014) found a negative correlation also between supporting and cultural services, and in particular between habitat provisioning and recreation. For example, evidence suggests that including rewilded areas within green areas has a positive effect on both biodiversity and psychological restoration, but they are also unsafe for particular social groups, such as women (Mexia et al., 2018).
4. Negative correlation has been found also between the provisioning, regulating, supporting and cultural services. In fact, urban greening may result in “green gentrification” as neighborhood improvements bring about rising property values, social exclusion, and displacement (Scott et al., 2016; Pearsall and Eller 2020).

On the other side, few positive interactions – synergies – between different ES have been found at the urban scale. More in detail, a positive correlation exists between regulating and cultural services. In fact, Schirpke et al. (2019), Sylla et al. (2020) found that the recreational potential with nutrient cycling positively reinforced each other.

Little literature on ES disservices, trade-offs and synergies and weather the elimination of these trade-offs is achievable is available (Bennett et al., 2009; Martín-López et al., 2012; Torralba et al., 2018). Some authors argue that the assessment of ES urban trade-offs and synergies is key to design policy instruments and to plan ad hoc NBS (Haase et al., 2012; Eggermont et al., 2015).

Understanding how the provision of ES from NBS is related to the structure and social context of the urban landscape and measure their impacts of development in time and space is important for promoting the development of sustainable cities (Carpenter et al., 2006; Liu et al., 2007). In fact, as stated by Folke et al. (2002) cities have to be considered as socio-ecological systems with strongly connected components that evolve as integrated systems and ecosystems are part of them. So, to strategically plan and inform policy for the development of NBS it is necessary to be able to characterize and measure their impacts in time and space.

1.2.2 The economic valuation of ES

As previously described, NBS can enhance a wide range of ecosystem services that are able to provide economic, social, and environmental benefits in cities. Some ecosystem services, such as provisioning services, are exchanged on markets so they can be evaluated through prices, but many other services present characteristics of public goods and markets cannot capture their value. Consequently, price signals do not correctly indicate the scarcity of natural capital from which the ecosystem services originate. Economic valuation can show the "hidden" values of natural capital and of its services. The logic behind the valuation of ecosystem services is to reveal the socio-economic impacts and to explain how human choices and activities can affect ecosystem functions. The topic has been analyzed by several studies within the category of market failures (TEEB, 2010): ecosystem services are characterized as externalities that do not find adequate remuneration (and protection) since are used without any cost by consumers.

Several policy instruments can be adopted in these circumstances, to modify the choices of economic actors through command and control, economic convenience, and availability of information. Effective and efficient use of these instruments requires to establish the value of ecosystem services. Assessing the economic value of ecosystem services is fundamental to manage and protect them and to define appropriate compensation mechanisms aimed to internalize the externalities generated by human activities. In literature, there are several methodologies for the evaluation of ecosystem services (System of Environmental-Economic Accounting Experimental Ecosystem Accounting adopted by United Nations Statistical Commission, Mapping and Assessment of Ecosystems and their Services - MAES Urban developed by the European Joint Research Centre JRC, etc.). The Economics of Ecosystems and Biodiversity - TEEB (2010) requires considering the Total Economic Value (TEV) generated by ecosystem services, defined as the sum of the values of all the services that natural capital flows generate.

The values generated are divided into: i) *use value*: direct (benefits obtained from the direct use of services), indirect ("public services" that do not find a value on the markets) and option (related with the importance that people give to future availability); ii) *non-use value*: existence (satisfaction that individuals derive from the existence of ecosystems), heritage (inter-generational equity) and altruism (intra-generational equity) (Gomes-Bazzethun and de Groot, 2011).

In the first case, it is possible to use direct evaluation methodologies based on the markets that reflect the actual preferences or costs for individuals (market priced based, cost-based and production function-based approaches). In the second case, the methodologies used for the evaluation have to be based on surrogated markets to investigate the preferences in terms of willingness to pay for a service through interviews and surveys (contingent evaluation, group evaluation, and modelling choice). The methodologies used for the evaluation/accounting of the services provided by the ecosystems are different and often the combination of several assessment methods is necessary. For example, the methodology of avoided costs and replacement costs are often used to calculate the values of regulation services such as atmospheric pollution, climate mitigation and microclimatic regulation (Sander et al., 2010).

Nowadays, impacts generated by NBS are not valued in a consistent and complete way. There is the need to compile a more comprehensive evidence base on the social, economic, and environmental effectiveness of NBS, since the current knowledge base is rather dispersed and fragmented. "The valuation (monetary and non-monetary) of the multiple benefits of NBS and the development of performance indicators, standards, technical and scientific reference models for NBS is necessary for their wider and systemic implementation", as well as the availability of tailored assessment tools (EC, 2015).

1.3 Policy instruments to foster the implementation of NBS in cities

As emerged from the previous analysis, NBS are viewed as multifunctional and integrated policy approaches using nature to achieve broader policy objectives, and they are at the sharp end of the implementation of integrated climate change adaptation and mitigation actions at local scales (Bennett et al., 2016; Kirsop-Taylor, at al., 2021) (see chapter 4). The enhancement of ES depends also on the capacity of local governments to introduce policy instruments to facilitate the implementation and management of NBS in cities (Naeem et al., 2015).

“Operationalization of NBS as element around which policies are developed is manifest in the choice and design of policy instrument that supports the policy objectives” (Kirsop-Taylor, at al., 2021). Policy instruments are defined as “myriad techniques at the disposal of governments to implement their policy objectives” (Howlett, 1991). Jordan et al (2013) frame policy instruments as the tools used to attain policy goals. Several authors provided a classification of the policy instruments that can be adopted at the urban level for the integration of NBS and for the enhancement of the ES provided by them into local policymaking and decision-taking. The most common classification considers three types of instruments used in environmental policy: i) regulatory; ii) informational/knowledge-based, and iii) market-based instrument (Jordan et al., 2013).

Regulatory instruments constitute a prescriptive form of governing, through which targets are established and then implemented by public and private actors (Jordan et al., 2011). Regulatory instruments include standards, bans, limits, land use planning, etc. Many studies discussed the adoption of regulatory instruments at the urban scale for ensuring the uptake of NBS and the enhancement and protection of ES. These were legislative tools for coercing engagement and compliance with certain aspects of NBS in the city such as regulations for natural urban drainage, afforestation, climate change mitigation and adaptation, and land use regulation (Davis and Naumann, 2017; Papparlardo and La Rosa, 2020; Baulenas and Sotirov, 2020; Kirsop-Taylor, at al., 2021).

Informational/knowledge-based instruments are designed to provide information to social actors to change their behavior (Howlett and Ramesh 1995; Jordan et al., 2011). Informational/knowledge-based instruments for urban NBS implementation have been considered and analyzed as experiments (Davis and Naumann, 2017; Raymond et al., 2017; Zwierzchowska et al., 2019; Baravikova, 2020; Frantzeskaki et al., 2020). Informational/knowledge-based instruments included information-related instruments like environmental education, eco-labelling, awareness raising campaigns, information about NBS impacts at the city level, etc.

Market-based instruments are defined as instruments aimed to "address the market failure of environmental externalities either by incorporating the external cost of production or consumption activities through taxes or charges on processes or products, or by creating property rights and facilitating the establishment of a proxy market for the use of environmental services" (OECD, 2007). Given that ES are positive externalities - provided by NBS - the proposed policy instrument has to ensure their internalization for the ES socially optimal provision. In line with economic theory, this can be achieved through a transaction between the beneficiaries and the providers of the services in question, which may take different forms, and either be direct or imply third parties (Froger et al., 2015). Various options can be followed: taxes, subsidies, incentives, trading schemes, contracts between service providers and beneficiaries, etc. At the urban scale, market-based instruments took the form of limited incentive schemes for the setting up on NBS experiments, and revenue generation schemes for the maintenance of NBS schemes (Kirsop-Taylor, at al., 2021).

Despite this, in the last years, there has been a gradual shift from the adoption of regulatory mechanisms to instruments based on incentives, compensations and voluntary agreements linked to the creation of new markets. Mendonça et al. (2021) analyzed the literature linked to the instruments used for the implementation of NBS. The results show that, considering each instrument in total, regulatory instruments appear in ~89% of the papers, marker based in ~61% and information/knowledge-based in ~57% of the reviewed papers. Market based instruments were the second most mentioned type of instrument in the literature (almost 61%). Specific economic instruments in the assessed studies include taxes, subsidies, incentives, and cost internalization. Droste et al. (2017) introduced three types of economic instruments: i) price instruments, ii) quantity instruments, and iii) fiscal instruments. Two of them address private actors through either prices or quantity mechanisms and one addressing public actors such as municipalities which help in accomplishing NBS.

The adoption of price instruments can take place through the definition of incentives or through the use of existing charges or the imposition of new ones (e.g., water charges). Incentives and charges can modify the price of using an ecosystem service to reflect the full cost of its provision. These types of instruments are based on the cost recovery principle and often they include only the technical costs sustained for the services provisioning (Dorste et al., 2017). However, there exist margins herein, as the determination of underlying costs allows – at least in principle – to also include environmental and resource costs (Gawel 2016; Rüger et al. 2015). Quantitative instruments aim to define limits for the activities that generate a negative impact on natural resources that are directly limiting activities impacting natural areas such as cap and trade schemes for land use (Dorste et al., 2017). Fiscal instruments focus on the decision makers in the public sector by creating incentives for developing green infrastructures and NBS through the inclusion of ecological criteria in fiscal transfer processes (Dorste et al., 2017). For example, in Portugal and in Brazil ecological fiscal transfers have been implemented: municipalities receive tax revenues for hosting protected areas (Santos et al. 2012).

Different studies (Dorste et al., 2017; Sarabi et al., 2019) considered the marked based instrument as enabler for NBS adoption at the urban scale. Despite this, according to Hawxwell et al. (2019), economic instruments may also represent a barrier for NBS implementation, depending on how they are formulated. In fact, market-based instruments should be tailored to the local environment and conditions, creating a realistic, attractive, and viable context for the adoption of NBS. Moreover, market-based instruments application can represent a greater challenge compared to the other two typologies (Mendonça et al., 2021).

Among market-based instruments, special attention should be dedicated to the Payments for Ecosystem Services (PES) which aim to stimulate the production of positive externalities, transforming them into real products that can be bought and sold on a market. In other words, payments for ecosystem services are tools that aim to change the behaviors that have negative impacts on ecosystems and the goods produced by introducing the economic value of ecosystem services in decision-making. A PES can be defined as a voluntary transaction between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services (Wunder, 2015). Applying PES in an urban context is far more challenging than in rural areas, where there is a less complex set of stakeholders and where computing benefits and costs is more straightforward (Davies et al., 2018). Indeed, the complexity of urban environments and the interactions between many ES requires a holistic perspective to ensure that the maximum benefits can accrue to beneficiaries from the combined outputs of individual schemes (Richards and Thompson, 2018).

2 Assessing the multiple benefits of NBS: innovative approaches and KPIs

Abstract

Nature-based solutions (NBS) generate different impacts at the urban scale, such as the ability to regulate water or store carbon, comparable to traditional, grey infrastructures in a more cost-efficient way. On the other hand, by their intrinsic nature, NBS do deliver a series of other services that are commonly defined as social, economic, and environmental co-benefits. These benefits are not always valued in a consistent and complete way so there is the need to compile a more comprehensive evidence base on the social, economic, and environmental effectiveness of NBS. The chapter attempts to identify a categorization of the existing NBS and to define the ecosystem services provided by them. Furthermore, starting from the results achieved through the definition of the existing NBS frameworks assessment, the chapter will identify a set of KPIs, based on the ES produced by NBS, to measure the economic, social, and environmental benefits generated in by NBS at the urban level taking into account their multifunctional character. In total, 66 indicators have been individuated: 3 for provisioning services, 38 for regulating services, 17 for cultural services and 8 for supporting services. Each indicator has been associated to a category of ES to measure and evaluate the performances of NBS implemented in cities.

2.1 Possible classifications of NBS typologies

Nature-based solutions (NBS) generate different impacts at the urban scale, such as the ability to regulate water or store carbon, comparable to traditional, grey infrastructures in a more cost-efficient way. On the other hand, by their intrinsic nature NBS do deliver a series of other services that are commonly defined as social, economic, and environmental co-benefits. However, these benefits are not valued in a consistent and complete way (Croci et al., 2021). There is the need to compile a more comprehensive evidence base on the social, economic, and environmental effectiveness of NBS. In fact, NBS have the ability to reinforce ecosystem services (ES) at urban level. Several NBS can be implemented in cities: green roofs and walls, urban parks and gardens, green corridors, river stream restoration, streets greening, urban farming, sustainable urban drainage systems, temporary flooding areas, and urban forests. As already highlighted, important urban ES provided by NBS include: i) reduction of local air pollution (Gomez-Baggethun et al., 2013); ii) microclimatic regulation: heat island phenomenon reduction and temperature increase due to climate change (Schwarz et al., 2011); iii) direct health benefits, such as a lower prevalence of asthma in early childhood (Lovasi et al 2008) iv) mortality reduction, and general health improvements (Maas et al 2006; Mitchell and Popham, 2008; van de Bosh and Ode Sang, 2017); flood risk reduction (Cohen et al., 2016); vi) quality of life improvement: social inclusion, safety, cultural aspects (van de Bosh and Ode Sang, 2017).

Several studies (Escobedo and Nowak, 2008; Churkina, 2017) confirm that urban vegetation has positive effects on air quality by eliminating polluting determinants, altering the urban microclimate, and reducing temperatures through the produced shadow, the evapotranspiration processes, attenuating the winds and decreasing the energy consumption of the buildings, also generating a reduction in CO_2 emissions from power plants. These services are generated by a diverse set of land uses, including parks, waterways, avenues, gardens and courtyards, docks, municipalities, green roofs, and facades, etc. Furthermore, the dependence of cities on the surrounding landscape and its biodiversity is essential to support the production, enhancement, and maintenance of ES and to guarantee the resilience of urban systems as a whole. Despite this, there is currently a lack of tools to evaluate impacts and benefits generated by NBS.

Starting from the results achieved through the definition of the existing NBS frameworks assessment, the chapter will identify a set of KPIs, based on the ES produced by NBS, to measure the economic, social, and environmental benefits generated in by NBS at the urban level considering their multifunctional character.

Currently, several sets of KPIs have been identified to measure the social, economic, and environmental status in cities. KPIs focused on cities are collected in the ISO 37120: "*Sustainable development of communities-Indicators for city services and quality of life*". A next step on ISO standards on cities, refers to the ISO 37121 "*Resilient cities*" suggesting indicators that consider risk and vulnerability, institutional and response capacity, and outcomes. Furthermore, in the last years several sets of KPIs related to the measurement of the contribution of cities to the achievement of the SDGs – such as the SDG Voluntary Local reviews (JRC, 2020) SDG Index and Dashboards Report for European Cities (SDSN, 2019) - have been defined. However, there is no specific mention for KPIs related to NBS and the interaction with social science and humanities and/or co-creation concepts. Since NBS can generate a wide range of impacts in cities it is necessary to adopt a comprehensive approach to consider all these impacts and to correctly evaluate the contribution of NBS to well-being improvement in cities.

Different assessment framework for the valuation of the contribution of NBS in cities have been identified. Some of these frameworks have been defined with the main purpose of including all the benefits generated by NBS to be able to catch the multifunctional character of NBS. These are: the MAES Urban (MAES Urban, 2016), the EKLIPSE Framework (Raymond et al., 2017) and the TEEB for cities (TEEB, 2011). The three frameworks have been defined from different starting points, the MAES urban and the TEEB for cities are based on the ES approach, on the contrary the EKLIPSE framework is based on the urban challenges NBS can contribute to. As already highlighted in the previous book chapters, there are several NBS that can be implemented at the urban level to reinforce and enhance the provision of ES. Table 2 summarizes a comprehensive list of NBS that can be adopted at the urban level. The table also includes the scale of the impacts generate by each NBS. In fact, to measure the impacts generated by NBS it is also necessary to identify the scale of the impact generated. In fact, different types of NBS can have impacts on the entire urban area (e.g., ecological corridor), while others have a more localized impact (e.g., green wall). In this regard, five impact scales are reported, which have been considered in the definition of the indicators for the evaluation of NBS. The impact scales considered are:

- Regional Scale (R): Urban unit superior to metropolitan area, with a center in a large city, which subordinates to it the productive, tertiary and other activities of the entire region;
- Metropolitan (M): It is an urban region that encompasses a central city (the metropolis) that gives its name to the area and a series of cities that can function as dormitory, industrial, commercial and service cities;
- Urban (U): City, town, village without its metropolitan area;

- Street (S): Thoroughfare of a population that is generally limited on both sides by blocks or rows of buildings;
- Building (B): Type of construction made from solid materials and used to put people and objects up.

NBS Group	NBS type	Scale
Green route	Cycle and pedestrian green route	U
Arboreal Interventions	Shade trees	S
	Cooling trees	S
	Planting and renewal urban trees	U, S
	Arboreal areas around urban areas	U, M
	Trees re-naturing parking	S
Carbon capture	Urban carbon sink	U
SUDs	SUDs	U, S, M
	Grassed swales and water retention ponds	U, S, M
	Rain gardens	U, S
Flood actions	Urban catchment forestry	U, S, M
	Hard drainage-flood prevention Unearth water courses	R, U, M
	Channel re-naturing	U
	Floodable park	R, M, U
Water treatment	Green filter area	U
	Natural wastewater treatment	U
Green pavements and smart soils	Hard drainage pavements	S, U
	Green pavements green parking pavements	U
	Cycle-pedestrian green pavement	U
	Cool pavement	U, S
	Smart soil production in climate-smart urban farming	S, U
	Smart soil as substrate	U
Pollinator	Pollinator verges and spaces	S, U
	Pollinators walls/vertical	B
	Pollinator roofs	B
	Natural and compacted pollinator´s modules	U
Vertical GI	Green fences	S, B
	Green noise barriers	S
	Green façade with climbing plants	B
	Hydroponic green façade	B
	Vertical mobile garden	S
Horizontal GI	Floating gardens	S
	Green covering shelters	B
	Electro wetland	U
	Green roof	B
	Green shady structures	S

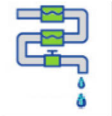
Pollutants filter	Green filter area	S
	Urban garden bio-filter	S, U
Resting areas	Parklets	S
	Green resting areas	U, S
Urban farming	Climate-smart greenhouses	S
	Urban orchards	U
	Community composting	U
Park and garden	Large urban public park	M, U, S
	Heritage garden	M, U
	Botanical garden	M, U
	Pocket garden/park	U, S
	Public urban green space (place, square, etc.)	M,U, S
	Private garden	S, B
	Wood	U, S, B
	Lawn	U, S, B
	Single tree	M, U, S, B
Urban network structures	Green tram track	U, S
	Street trees	S
	Green strip	M, U, S,
	Green waterfront	M, U, S,
	Unsealed parking lot	U, S,
	Green parking lot	U, S
Green walls	Climber green wall	S, B
	Green wall system	S, B
	Planter green wall	S, B
	Vegetated pergola	S, B
Urban green spaces management	Integrated pest management	R, M, U, S
	Integrated and ecological management: spatial aspects	R, M, U, S
	Integrated and ecological management	R, M, U, S
	Create and preserve habitats and shelters for biodiversity	R, M, U, S
Monitoring	Bio-indicators	R, M, U, S
Protection and conservation	Limit or prevent access to an area	R, M, U, S
	Limit or prevent specific uses and practices	R, M, U, S
Urban planning strategies	Ensure continuity with ecological network	M, U, S
	Planning tool to control urban expansion	M, U, S
Parks and garden	Urban green space with specific uses	M, U, S
Constructed wetlands and built structures for water management	Floodplains	R, M, U, S
	Vegetation engineering system for riverbanks erosion control	R, M, U, S
	De-sealed area	R, M, U, S
	Swale	R, M, U, S
	Constructed wetland for water treatment	R, M, U, S
Water bodies	Reopened stream	R, M, U, S
	Vegetable garden	U, S, B

Structures characterized by food and resources production	Urban orchard	U, S, B
	Urban forest	U, S,
	Composting	U, S, B
	Urban farm	U, S
	Urban vineyard	U, S
Works on Soil	Structural soil	R, M, U, S
	Soil improvement	R, M, U, S
	Mulching	R, M, U, S
Choice of plants	Use of pre-existing vegetation	R, M, U, S
	Introduced plants	R, M, U, S
	Vegetation diversification	R, M, U, S
Systems for erosion control	Soil and slope revegetation	R, M, U, S
	Strong slope revegetation	R, M, U, S
Green roofs	Intensive green roof	S, B
	Semi-intensive green roof	S, B
	Extensive green roof	U, S, B
Ecological restoration	Management of polluted areas by plants	M, U, S, B
Technological NBS	Urban clean water solution	U, S, B
	Ceramic Green Wall	S, B
	Light management / Adaptive Lighting	S, B
	Wood structure	S, B
	Luminescent Path	U, S,
	Food production	M, U, S, B
	Mobile vegetable Garden	U, S, B
	Grow Tile	U, S, B
Territorial NBS	Adaptive reuse of Urban network space	M, U, S, B
	Beehive provision and adoption	M, U, S, B
	Rainwater management and recirculation	M, U, S, B
	Tree planting solution - Groasis	M, U, S, B
	Renaturalization of Brownfields	M, U, S, B
	Watercourse restoration	M, U, S, B
	Urban vegetable gardens	U, S, B
	Rainwater management / Recirculation in residential Areas	U, S, B
	Wildlife park / Urban park/ Urban wetlands	M, U, S, B
	Green roof	U, S, B
	Autochthonous urban forest	U, S

Table 2: List or group of NBS identified and their respective scale

Capitalizing on the work done by several research projects and case studies that have been analyzed (URBAN GreenUP project catalogue, Nature4Cities project catalogue, URBINAT project catalogue, etc.), a tentative categorization of the different typologies of NBS has been provided to better understand which are the main challenges NBS can contribute to solve. In total 10 typologies of NBS have been identified. In this way, ten *NBS Categories* have been defined:

NBS for addressing and buffering Climate risks and impacts
NBS focused on reducing and mitigating impacts and risks provoked by climate change and extreme climate episodes.



NBS for addressing water quality and management
NBS focused on managing urban water in order to improve its quality, to avoid waste drinking water and to generate new ways to reuse it.

NBS for addressing air quality
NBS focused on improving air quality in cities through natural ways (green infrastructures) and transforming cities into more liveable spaces.

NBS for addressing urban biodiversity loss
NBS focused on increasing the urban biodiversity population and improving the living conditions for biodiversity in cities.

NBS for addressing soil management
NBS focused on improving soil quality and managing its use as way to provide services related to food provision.

NBS for promoting resources efficiency
NBS focused on the sustainable use of the resources as part of the provisioning and cultural services mainly. These NBS also contribute to support habitat services.

NBS for promoting sustainable energy consumption
NBS focused on the promotion of a sustainable use of energy considering the green mobility and the green spaces as solutions to save money and improve the living conditions in cities.

NBS for controlling Urbanization sprawling
NBS focused on breaking the uncontrolled expansion of cities through green planning development and establishing real green limits.

NBS for addressing Public Health and Well-being
NBS focused on improving the liveability of cities through NBS related to health and wellbeing.

NBS for addressing Environmental Justice and Social Cohesion
NBS focused on avoiding the inequality in cities, promoting community and participatory processes as a way to generate a green social cohesion and justice.

Finally, the identification of the ES provided by the different categories of NBS listed above have been carried out, furthermore also the scale of impact has been included in the analysis. Table 3 summarizes the 10 categories of NBS individuated, each NBS included in the different categories, and the ES provided by them. The analysis and selection of the KPIs to measure the performances of NBS in cities has been performed based on the ES that have been individuated and listed in Table 7.

CATHEGORY		NBS	ES
NBS for addressing and buffering Climate risks and impacts	- Shade trees (S) - Cooling trees (S) - Trees re-naturing parking (S) - Urban carbon sink (U) - SUDs (U, S, M) - Channel re-naturing (U) - Green pavements green parking pavements (U) - Cycle-pedestrian green pavement (U) - Cool pavement (U, S) - Green fences (S, B) - Green noise barriers (S) - Green façade with climbing plants (B) - Vertical mobile garden (S) - Floating gardens (S) - Green covering shelters (B) - Green roof (B) - Green shady structures (S)	- Parklets (S) - Green resting areas (S) - Climate-smart greenhouses (S) - Public urban green space (place, square, etc.) (M, U, S) - Single tree (M, U, S, B) - Street trees (S) - Green strip (M, U, S) - Green parking lot (U, S) - Integrated and ecological management: spatial aspects (R, M, U, S) - Urban forest (U, S) - Intensive green roof (S, B) - Semi-intensive green roof (S, B) - Extensive green roof (U, S, B) - Mobile vegetable Garden (U, S, B) - Grow Tile (U, S, B) - Tree planting solution – Groasis (M, U, S, B) - Renaturalization of Brownfields (M, U, S, B) - Urban vegetable gardens (U, S, B) - Autochthonous urban forest (U, S)	- Food supply - Fresh water supply - Wood, pulp, other - Urban Temperature - Climate regulation - Water purification - Pollination - Erosion control - Human diseases - Barriers effect of vegetation - Tourism - Recreation - Spirituality - Cognitive development - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Maintenance genetic diversity - Biomass production - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes.
NBS for addressing water quality and management	- SUDs (U, S, M) - Grassed swales and water retention ponds (U, S, M) - Rain gardens (U, S, M) - Urban catchment forestry (U, S, M) - Hard drainage-flood prevention Unearth water courses (R, U, M)	- Urban garden bio-filter (S, U) - Green waterfront (M, U, S) - Integrated and ecological management: spatial aspects (R, M, U, S) - Floodplains (R, M, U, S) - Vegetation engineering system for riverbanks erosion control (R, M, U, S)	- Fresh water supply - Wood, pulp, other - Food and fibre - Water purification - Erosion control - Human diseases - Nutrient regulation

	- Channel re-naturing (U) - Floodable park (R, M, U) - Green filter area (U) - Natural wastewater treatment (U) - Hard drainage pavements (S, U) - Green pavements green parking pavements (U) - Electro wetland (U)	- De-sealed area (and associated systems, (R, M, U, S) - Swale (R, M, U, S) - Constructed wetland for water treatment (R, M, U, S) - Reopened stream (R, M, U, S) - Urban clean water solution (U, S, B) - Watercourse restoration (M, U, S, B) - Rainwater recirculation in residential Areas (U, S, B) - Wildlife park / Urban park/ Urban wetlands (M, U, S, B)	- Recreation - Cognitive development - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Maintenance genetic diversity - Biomass production - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes
NBS for addressing air quality	- Cycle and pedestrian green route (U) - Planting and renewal urban trees (U, S) - Arboreal areas around urban areas (U, M) - Urban carbon sink (U) - Green fences (S, B) - Green noise barriers (S) - Green façade with climbing plants (B) - Hydroponic green façade (B) - Vertical mobile garden (S) - Floating gardens (S) - Green covering shelters (B) - Green shady structures (S) - Green filter area (S) - Urban garden bio-filter (S, U) - Parklets (S) - Green resting areas (U, S) - Climate-smart greenhouses (S) - Large urban public park (M, U, S) - Heritage garden (M, U) - Botanical garden (M, U) - Pocket garden/park (U, S)	- Green waterfront (M, U, S) - Green parking lot (U, S) - Climber green wall (S, B) - Green wall system (S, B) - Planter green wall (S, B) - Vegetated pergola (S, B) - Integrated and ecological management (R, M, U, S) - Bio-indicators (R, M, U, S) - Urban green space with specific uses (school playgrounds, campgrounds, sport field, etc.) (M, U, S) - Vegetable garden (U, S, B) - Urban forest (U, S) - Use of pre-existing vegetation (R, M, U, S) - Introduced plants (R, M, U, S) - Vegetation diversification (R, M, U, S) - Intensive green roof (S, B) - Semi-intensive green roof (S, B) - Extensive green roof (U, S, B)	- Medicines - Genetic resources - Pollination - Human diseases - Barriers effect of vegetation - Tourism - Recreation - Spirituality - Cognitive development - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Maintenance genetic diversity - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes

	- Green cemetery (M, U, S) - Public urban green space (M, U, S) - Private garden (S, B) - Wood (U, S, B) - Lawn (U, S, B) - Single tree (M, U, S, B) - Green tram track (U, S) - Street trees (S) - Green strip (M, U, S)	- Management of polluted areas by plants (M, U, S, B) - Ceramic Green Wall (S, B) - Wood structure (S, B) - Mobile vegetable Garden (U, S, B) - Grow Tile (U, S, B) - Tree planting solution – Groasis (M, U, S, B) - Renaturalization of Brownfields (M, U, S, B) - Urban vegetable gardens (U, S, B) - Wildlife park / Urban park/ Urban wetlands (M, U, S, B) - Green roof (U, S, B) - Autochthonous urban forest (U, S)	
NBS for addressing urban biodiversity loss	- Cycle and pedestrian green route (U) - Planting and renewal urban trees (U, S) - Arboreal areas around urban areas (U, M) - Trees re-naturing parking (S) - Urban carbon sink (U) - Pollinator verges and spaces (S, U) - Pollinators walls/vertical (B) - Pollinator roofs (B) - Natural pollinator´s modules (U) - Compacted pollinator´s modules (U) - Green fences (S, B) - Green noise barriers (S) - Green façade with climbing plants (B) - Hydroponic green façade (B) - Vertical mobile garden (S) - Floating gardens (S) - Green covering shelters (B) - Electro wetland (U) - Green roof (B) - Green shady structures (S)	- Single tree (M, U, S, B) - Street trees (S) - Green strip (M, U, S) - Green parking lot (U, S) - Climber green wall (S, B) - Green wall system (S, B) - Planter green wall (S, B) - Vegetated pergola (S, B) - Integrated pest management (R, M, U, S) - Integrated and ecological management (R, M, U, S) - Preserve habitats and shelters for biodiversity (R, M, U, S) - Bio-indicators (R, M, U, S) - Ensure continuity with ecological network (M, U, S) - Vegetable garden (U, S, B) - Urban orchard (U, S, B) - Urban forest (U, S) - Use of pre-existing vegetation (R, M, U, S)	- Food supply - Wood, pulp, other - Medicines - Genetic resources - Food and fibre - Pollination - Human diseases - Nutrient regulation - Barriers effect of vegetation - Tourism - Recreation - Spirituality - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Maintenance genetic diversity - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes

	- Green filter area (S) - Urban garden bio-filter (S, U) - Parklets (S) - Green resting areas (U, S) - Large urban public park (M, U, S) - Heritage garden (M, U) - Botanical garden (M, U) - Pocket garden/park (U, S) - Green cemetery (M, U, S) - Public urban green space (M, U, S) - Beehive provision and adoption (M, U, S, B) - Private garden (S, B)	- Introduced plants (R, M, U, S) - Vegetation diversification (R, M, U, S) - Intensive green roof (S, B) - Semi-intensive green roof (S, B) - Extensive green roof (U, S, B) - Management of polluted areas by plants (phytoremediation) (M, U, S, B) - Mobile vegetable Garden (U, S, B) - Tree planting solution - Groasis (M, U, S, B) - Urban vegetable gardens (U, S, B) - Green roof (U, S, B) - Autochthonous urban forest (U, S)	
NBS for addressing soil management	- Enhanced nutrient managing and releasing soil (S) - Smart soil production in climate-smart urban farming precinct (S, U) - Smart soil as substrate (U) - Large urban public park (M, U, S) - Wood (U, S, B) - Lawn (U, S, B) - Integrated and ecological management: time and frequency aspects Sustainable use of fertilisers (R, M, U, S) - Urban green space with specific uses (school playgrounds, campgrounds, sport field, etc.) (M, U, S) - Vegetation engineering system for riverbanks erosion control (R, M, U, S) - De-sealed area (and associated systems, ex. Permeable paving) (R, M, U, S) - Structural soil (R, M, U, S) - Soil improvement (R, M, U, S) - Soil and slope revegetation (R, M, U, S) - Strong slope revegetation (R, M, U, S) - Wildlife park / Urban park/ Urban wetlands (M, U, S, B)		- Food supply - Fresh water supply - Wood, pulp, other - Food and fibre - Water purification - Pollination - Erosion control - Nutrient regulation - Waste treatment and assimilation - Tourism - Recreation - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary
NBS for promoting resources efficiency	- Planting and renewal urban trees (U, S) - Rain gardens (U, S) - Urban catchment forestry (U, S, M)	- Limit or prevent access to an area (R, M, U, S) - Limit or prevent specific uses and practices (R, M, U, S)	- Food supply - Fresh water supply - Wood, pulp, other - Medicines

	- Hard drainage-flood prevention Unearth water courses (R, U, M) - Floodable park (R, M, U) - Green filter area (U) - Natural wastewater treatment (U) - Enhanced nutrient managing and releasing soil (S) - Smart soil production in climate-smart urban farming precinct (S, U) - Smart soil as substrate (U) - Hydroponic green façade (B) - Electro wetland (U) - Climate-smart greenhouses (S) - Urban orchards (U) - Community composting (U) - Wood (U, S, B) - Lawn (U, S, B) - Single tree (M, U, S, B) - Green tram track (U, S) - Integrated pest management (R, M, U, S) - Integrated weed management (R, M, U, S - Integrated and ecological management: spatial aspects (R, M, U, S) - Integrated and ecological management (R, M, U, S)	- Ensure continuity with ecological network (M, U, S) - Planning tool to control urban expansion (M, U, S) - Urban green space with specific uses (school playgrounds, campgrounds, sport field, etc.) (M, U, S) - Urban orchard (U, S, B) - Urban forest (U, S) - Composting (U, S, B) - Urban farm (U, S) - Urban vineyard (U, S) - Structural soil (R, M, U, S) - Soil improvement (R, M, U, S) - Mulching (R, M, U, S) - Use of pre-existing vegetation (R, M, U, S) - Introduced plants (R, M, U, S) - Vegetation diversification (R, M, U, S) - Management of polluted areas by plants (M, U, S, B) - Urban clean water solution (U, S, B) - Light management / Adaptive Lighting (S, B) - Food production (M, U, S, B) - Adaptive reuse of Urban network space (M, U, S, B) - Wildlife park / Urban park/ Urban wetlands (M, U, S, B)	- Genetic resources - Food and fibre - Urban Temperature - Climate regulation - Water purification - Nutrient regulation - Waste treatment and assimilation - Tourism - Recreation - Cognitive development - Biomass production - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes
NBS for promoting sustainable energy consume	- Hard drainage-flood prevention Unearth water courses (R, U, M) - Floodable park (R, M, U) - Green filter area (U) - Natural wastewater treatment (U) - Hard drainage pavements (S, U)	- Integrated and ecological management: time and frequency aspects Sustainable use of fertilisers (R, M, U, S) - Take into account the distribution of green spaces through the city (M, U, S) - Urban orchard (U, S, B)	- Food supply - Fresh water supply - Wood, pulp, other - Medicines - Food and fibre - Urban Temperature

	- Smart soil production in climate-smart urban farming precinct (S, U) - Smart soil as substrate (U) - Hydroponic green façade (B) - Electro wetland (U) - Urban garden bio-filter (S, U) - Parklets (S) - Community composting (U) - Wood (U, S, B) - Integrated pest management (R, M, U, S) - Integrated weed management (R, M, U, S) - Integrated and ecological management: spatial aspects (R, M, U, S)	- Urban forest (U, S) - Composting (U, S, B) - Urban farm (U, S) - Mulching (R, M, U, S) - Use of pre-existing vegetation (R, M, U, S) - Light management / Adaptive Lighting (S, B) - Wood structure (S, B) - Urban mushroom Farm (U, S) - Luminescent Path (U, S) - Food production (M, U, S, B) - Rainwater management and recirculation in residential areas (M, U, S, B)	- Climate regulation - Water purification - Human diseases - Nutrient regulation - Waste treatment and assimilation - Tourism - Recreation - Spirituality - Maintenance genetic diversity - Biomass production - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary
NBS for controlling Urbanization sprawling	- Cycle and pedestrian green route (U) - Arboreal areas around urban areas (U, M) - Large urban public park (M, U, S) - Heritage garden (M, U) - Botanical garden (M, U) - Pocket garden/park (U, S) - Green cemetery (M, U, S) - Public urban green space (M, U, S) - Private garden (S, B) - Single tree (M, U, S, B) - Integrated and ecological management: spatial aspects (R, M, U, S) - Limit or prevent access to an area (R, M, U, S) - Limit or prevent specific uses and practices (R, M, U, S) - Ensure continuity with ecological network (M, U, S) - Take into account the distribution of green spaces through the city (M, U, S)	- Planning tool to control urban expansion (M, U, S) - Urban green space with specific uses (school playgrounds, campgrounds, sport field, etc.) (M, U, S) - Floodplains (R, M, U, S) - Intensive green roof (S, B) - Semi-intensive green roof (S, B) - Extensive green roof (U, S, B) - Management of polluted areas by plants (phytoremediation) (M, U, S, B) - Urban clean water solution (U, S, B) - Adaptive reuse of Urban network space (M, U, S, B) - Rainwater management and recirculation in residential areas (M, U, S, B) - Rainwater management / Recirculation in residential Areas (U, S, B) - Wildlife park / Urban park/ Urban wetlands (M, U, S, B)	- Food supply - Fresh water supply - Wood, pulp, other - Medicines - Genetic resources - Food and fibre - Urban Temperature - Climate regulation - Water purification - Pollination - Erosion control - Human diseases - Nutrient regulation - Waste treatment and assimilation - Tourism - Recreation - Spirituality - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values

		- Autochthonous urban forest (U, S)	- Maintenance genetic diversity - Biomass production - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes
NBS for addressing Public Health and Well-being	- Cycle and pedestrian green route (U) - Cooling trees (S) - Planting and renewal urban trees (U, S) - Arboreal areas around urban areas (U, M) - Trees re-naturing parking (S) - Urban carbon sink (U) - Green pavements green parking pavements (U) - Cycle-pedestrian green pavement (U) - Cool pavement (U, S) - Pollinator verges and spaces (S, U) - Pollinators walls/vertical (B) - Pollinator roofs (B) - Natural pollinator´s modules (U) - Compacted pollinator´s modules (U) - Green noise barriers (S) - Green façade with climbing plants (B) - Vertical mobile garden (S) - Floating gardens (S) - Green covering shelters (B) - Green roof (B) - Urban garden bio-filter (S, U) - Parklets (S) - Green resting areas (U, S) - Urban orchards (U) - Community composting (U) - Large urban public park (M, U, S)	- Street trees (S) - Green wall system (S, B) - Planter green wall (S, B) - Vegetated pergola (S, B) - Integrated pest management (R, M, U, S) - Preserve habitats and shelters for biodiversity (R, M, U, S) - Limit or prevent access to an area (R, M, U, S) - Limit or prevent specific uses and practices (R, M, U, S) - Ensure continuity with ecological network (M, U, S) - Planning tool to control urban expansion (M, U, S) - Urban green space with specific uses field, etc.) (M, U, S) - Urban orchard (U, S, B) - Urban forest (U, S,) - Urban farm (U, S) - Urban vineyard (U, S) - Structural soil (R, M, U, S) - Vegetation diversification (R, M, U, S) - Intensive green roof (S, B) - Semi-intensive green roof (S, B) - Extensive green roof (U, S, B) - Management of polluted areas by plants (M, U, S, B)	- Food supply - Fresh water supply - Wood, pulp, other - Medicines - Genetic resources - Food and fibre - Urban Temperature - Climate regulation - Water purification - Human diseases - Nutrient regulation - Waste treatment and assimilation - Tourism - Recreation - Spirituality - Cognitive development - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Maintenance genetic diversity - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary processes

	- Heritage garden (M, U) - Botanical garden (M, U) - Pocket garden/park (U, S) - Public urban green space (M, U, S)	- Urban clean water solution (U, S, B) - Light management / Adaptive Lighting (S, B) - Mobile vegetable Garden (U, S, B) - Beehive provision and adoption (M, U, S, B) - Tree planting solution - Groasis (M, U, S, B) - Renaturalization of Brownfields (M, U, S, B) - Urban vegetable gardens (U, S, B) - Wildlife Park / Urban park/ Urban wetlands (M, U, S, B) - Green roof (U, S, B)	
NBS for addressing Environmental Justice and Social Cohesion	- Parklets (S) - Green resting areas (U, S) - Urban orchards (U) - Community composting (U) - Large urban public park (M, U, S) - Heritage garden (M, U) - Botanical garden (M, U) - Pocket garden/park (U, S) - Green cemetery (M, U, S) - Wood (U, S, B) - Lawn (U, S, B) - Vegetable garden (U, S, B) - Urban orchard (U, S, B) - Urban forest (U, S) - Urban farm (U, S)	- Urban vineyard (U, S) - Mulching (R, M, U, S) - Food production (M, U, S, B) - Mobile vegetable Garden (U, S, B) - Adaptive reuse of Urban network space (M, U, S, B) - Beehive provision and adoption (M, U, S, B) - Urban vegetable gardens (U, S, B) - Wildlife Park / Urban Park/ Urban wetlands (M, U, S, B)	- Food supply - Fresh water supply - Medicines - Food and fiber - Water purification - Human diseases - Waste treatment and assimilation - Tourism - Recreation - Spirituality - Cognitive development - Aesthetic experience as well as their role in supporting knowledge systems, social relations, and aesthetic values - Nutrient cycling, water cycling - Provisioning of habitat for species - Maintenance of genetic pools and evolutionary

Table 3: Categorization of NBS following the methodology stablished (the methodology considers the link among Urban Challenges, Urban ES and main NBS identified from existing NBS Catalogues). The NBS contained in this Categorization will be subjected to a continuous updating)

2.2 Measuring social, economic, and environmental impacts of NBS

The selection of a KPIs set for the assessment of NBS in cities should consider the plethora of impacts generated by NBS in cities with a special attention also at the disservices generated by NBS to have a complete vision of the performance of NBS in urban areas (see Chapter 1).

In fact, the design and planning of NBS in cities can also generate negative impacts. For example, NBS can decrease air pollution, which can generate a decrease in diseases related to air pollution, and as a secondary impact decrease the expenditure on the public health service. Or it is possible that through the increase of trees in urban areas the amount of CO_2 sequestered increases and that the heat island effect decreases, but at the same time, the concentration of trees can cause emissions of biogenic volatile organic compounds - VOCs - (Livesley et al., 2016) and create allergic reactions (Carianos et al., 2019). Therefore, a thorough analysis according to each local context is needed to select the right species, as well as the spatial arrangement and management procedures. Another example is the increase in biodiversity and vegetation in some areas of the city. Some studies show that increasing the biodiversity of green spaces increases the attractiveness of the areas and the well-being of visitors (Carrus et al., 2015; Sang and Ode Sang, 2015). At the same time, dense areas of vegetation can generate feelings of lack of security, and therefore limit their use (Peschardt and Stigsdotter, 2013). Therefore, while areas of dense vegetation could have positive environmental effects, they could have a reduced health impact, leading to avoidance of their use (Nordh et al., 2009; Hegetschweiler et al., 2017).

In literature, the main negative impacts related to the implementation of NBS in urban contexts have been highlighted. Some of these are classified as "ecosystem disservices". Ecosystem disservices are defined as “ecosystem functions that are perceived as negative for human well-being” (Lyytimäki and Sipilä 2009). These are closely related to physical and chemical processes. In fact, inefficiencies range from problems related to air quality with respect to certain types of plants (pollination and / or dispersion of substances), to damage caused to infrastructures, to obstruction or reduction of air or light circulation up to arrive at possible damage caused by the presence of free animals. These ecosystem "disservices" must be considered in the planning of NBS to assess the potential negative effects at the urban level (Gómez-Baggethun & Barton, 2013). In the identification of the indicators, the negative impacts indicated above were also taken into consideration.

The KPIs frameworks considered in the analysis have been selected starting from: the EKLIPSE framework, the European Green Capital Award, SDGs indicator framework, the Aichi Targets, the TEEB, the CICES and the MAES Urban (see Appendix I). The identification of the most suitable KPIs for the measurement of the impacts generated by NBS at the urban level has been performed based on the following criteria: i) relevance and coherence (with the ES framework), ii) application at the urban scale (possibility to use a specific indicator for them measurement of the ES also at the urban scale), iii) measurability (capacity of cities to identify and collect the data).

Through the analysis a list of 66 indicators have been individuated: 3 for provisioning services, 38 for regulating services, 17 for cultural services and 8 for supporting services. Each indicator has been associated to a category of ES to measure and evaluate the performances of NBS implemented in cities. The KPIs have been categorized based on the ES categories. The table below (Table 4) summarizes the KPIs identified per each category of ES and the dimensions considered. More in detail the following table summarizes the indicators selected for the measurement of the impacts generated by NBS at the urban level. In the table are included: i) the ecosystem services category; ii) the ES classification and iii) the indicators.

ES Category	ES Classification	KPI
Provisioning	Water cycle	Drinking water provision (m3 ha-1year-1)
		Water for irrigations purposes (m3 ha-1year-1)
	Food production	Production of food (ton ha-1 year-1)
Regulation	CO_2 sequestration and storage	Tons of carbon removed or stored per unit area per unit time, total amount of carbon (tons) stored in vegetation
		Comparison with calculations of carbon consumption of equivalent non-NBS actions (e.g., through Life Cycle Assessment).
		Allometric forest models of carbon sequestration, developed using proxy data obtained from Lidar data
		Growth rates derived from Forest Inventory Analysis
	Air quality regulation	Non-spatial indicators of gross quantities: annual amount of pollutants captured by vegetation
		Non-spatial indicators of net quantities: net air quality improvement (pollutants produced – pollutants captured + GHG emissions from maintenance activities)
		Non-spatial indicators of shares: share of emissions (air pollutants) captured/sequestered by vegetation
		Spatial indicators: pollutant fluxes per m2 per year
		Annual mean levels of fine particulate matter (e.g., PM2.5 and PM10) in cities (population weighted) concentration recorded ug/m3
		Trends in emissions NOX, SOX
		Trends in CFC emissions (chlorofluorocarbons (CFCs) in ODP
		Mean levels of exposure to ambient air pollution (population weighted) (proposed indicator for SDG target 3.9)
		Pollutants removed by vegetation (in leaves, stems and roots) (kg ha-1 year-1)
		air quality parameters Nox, VOC, PM etc
	Water quality regulation	Drinking water provision (m3 ha-1year-1)
		Water for irrigations purposes (m3 ha-1year-1)
	Noise reduction	Noise reduction rates applied to UGI within a defined road buffer dB(A) m-2 vegetation unit
	Temperature regulation	Decrease in mean or peak daytime local temperatures (oC)

		Measures of human comfort e.g., ENVIMET PET — Personal Equivalent Temperature, or PMV — Predicted Mean Vote.
		Heatwave risks (number of combined tropical nights (>20oC) and hot days (>35oC))
		use of Star tools to calculate projected maximum surface temperature reduction
		physical measurement of temperature in the demo sites
		Increased evapotranspiration measured/modelled
		Temperature reduction in urban areas (°C, % of energy reduction for cooling)
	Waste-water treatment	Flood peak reduction
		Reduction of drought risk (probability).
		Soil water storage capacity (mm)
		Soil water infiltration capacity (cm)
		Water retention capacity by vegetation and soil (ton/km2)
		Intercepted rainfall (m3/year)
	Run-off mitigation	Run-off coefficient in relation to precipitation quantities (mm/%)
	Pollination	Pollinator species increase
	Extreme events mitigation	Areas (ha) and population exposed to flooding
		Share of green areas in zones in danger of floods (%)
		Population exposed to flood risk (% per unit area)
		Areas (ha) and population exposed to flooding
		Shoreline characteristics and erosion protection
		Flooding characteristics
Cultural	Recreation and physical and mental health	Weighted recreation opportunities provided by Urban Green Infrastructure
		Reduction in chronic stress and stress-related diseases measured through repeated salivary cortisol sampling and hair cortisol; use cortisol slope and average cortisol levels as an indicator of chronic stress.
		Number and share of people being physically active (min. 30 min 3 times per week).

	Aesthetic appreciation and inspiration for art, culture, and design	Perceptions of citizens on urban nature
	Spirituality and sense of place	Senses, imagination, and thought being able to use the senses, to imagine, think, and reason about the environment, informed by indicators of levels of literacy, mathematics, and science knowledge.
	Tourism	Recreational (number of visitors, number of recreational activities) or cultural (number of cultural events, people involved, children in educational activities) value
	Education	Number of students benefiting from education and research about the benefits of urban green areas
	Urban regeneration	Conservation of built heritage resources: percentage of built from retained for culture.
		Reclamation of contaminated land: percentage of contaminated area reclaimed.
		Assessment of typology, functionality and benefits provided pre- and post-interventions
	Social justice	Accessibility (measured as distance or time) of urban green spaces for population
		Accessibility: distribution, configuration, and diversity of green space and land use changes
		Access to housing: affordability and choice
		Average share of the built-up area of cities that is open space for public use for all, by sex, age, and persons with disabilities
		Cognitive aspects: indicators of trust, attachment to neighborhood, practical help, tolerance, and respect
	New opportunities for economic development	Number of economic activities related to or located closer to green areas
	Creation of new jobs	Number of jobs created; gross value added
Supporting	Habitat for species	Estimates of species, individuals, and habitats distribution
		Increased connectivity to existing GI
		Invasive and planted species
		Forest area as a proportion of total land area
		Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type

		Biodiversity Habitat Index
		Trends in land degradation (proposed for SDG target 15.3)
		Urban green: Index of biodiversity, provision, and demand of ecosystem services.

Table 4: KPIs for NBS impact assessment

2.3 Indicators for impacts assessment and economic valuation

The evaluation of the impacts generated by NBS at city scale is a complex issue since it is necessary to take into account the multifunctionality of the NBS and the benefits they generate on the different domains: environmental, social and economic. The approach and the set of KPIs proposed in this chapter are based on the ES framework and on the research that have already carried out by several international project focused on the analysis of the impacts of NBS at the urban level.

Several NBS that can be implemented at the urban level to reinforce and enhance the provision of ES. The chapter provided a list of different NBS that can be adopted at the urban level including also the scale of the impacts generated by each NBS. Since different types of NBS can have impacts on the entire urban area (e.g.: ecological corridor) while others have a more localized impact (e.g.: green wall) the scale of the impact generated by each NBS have been defined. Furthermore, capitalizing on the work done by several research projects and case studies that have been analyzed a categorization of the different typologies of NBS has been provided to better understand which are the main challenges NBS can contribute to solve. In total 10 typologies of NBS have been identified. In this way, ten *NBS Categories* have been defined. Finally, the ES provided by the different categories of NBS have been individuated and based these ES a set of KPIs have been selected. In total the KPIs individuated are 66: 3 for provisioning services, 38 for regulating services, 17 for cultural services and 8 for supporting services. Each indicator has been associated to a category of ES to measure and evaluate the performances of NBS implemented in cities.

Measuring the impacts generated by NBS on an urban scale requires the definition of a monitoring system that is able to take into account the co-benefits and the trade-offs within and across the stages of implementation and decision-making (Ürge-Vorsatz et al., 2014). The assessment of environmental impacts was in many cases restricted to single challenge areas (e.g., biodiversity, ecosystems) and rarely addressed cross-sectoral impacts (e.g., links between biodiversity, and the economy). The research developed sets the stage for the development of further investigations aimed to identify and standardize the assessment frameworks that can be applied at the urban level to evaluate ES and to define the ranges of values provided by each ES and NBS. This could improve data availability and provide a better estimation of the impacts generated by natural resources at the urban level, thus supporting the definition of better policies for the enhancement of natural resources and NBS.

3 Valuing nature based solution at the urban level

Abstract

The chapter critically analyses the methodologies that can be adopted to value ecosystem services (ES) at the urban level through a literature review. While literature on ES valuation has grown in recent years, its application to urban contexts is still limited.

25 papers, selected among 80 papers detected through keywords, carry out an economic valuation and so have undergone an in-depth analysis. 6 different valuation methodologies have been employed in 29 case studies. Some ES have been gauged at the urban level more often: the most considered ES for valuation are air quality regulation, local climate regulation, carbon sequestration and storage (belonging to regulating services category), and aesthetic appreciation and inspiration for culture, art, design (belonging to cultural services category). Some methodologies recur with a higher frequency in the valuation of ES at the urban level. Choice modeling and contingent valuation methodologies are used to value a variety of ES, including regulating, cultural, and supporting services. Other methodologies are used to value only specific ES. Replacement costs and damage cost avoided methodologies are used for the assessment of regulation services only; travel cost method and contingent valuation are used for cultural services only.

Results indicate that considered valuation methodologies show different levels of appropriateness with respect to specific ES categories. Therefore, there is a need to expand the application of valuation methodologies to capture the value of all ES provided by natural resources to protect and enhance them.

3.1 Economic valuation of ecosystem services provided by NBS

The protection and the enhancement of natural resources and NBS are fundamental to ensure the correct functioning of ecosystems at different scales, from global to local. A better understanding of the economic value generated by NBS, and ES they provide, can facilitate the adoption of efficient policies and measures to preserve and enhance them (Keyzer et al., 2009; Hailu, 2013). The monetary valuation of ES is traditionally absent from economic accounting so that their production ordinarily fails to reach social optimum conditions. As a result, their critical contributions are not considered in public, corporate, and individual decision-making (Kumar et al., 2013).

Public goods, such as water and air, are characterized by non-excludability and non-rivalry. The former entails that it is not possible to selectively exclude some individuals from their use, while the latter entails that consumption by one individual does not reduce its availability to others. Other environmental goods such as urban parks are closer to the category of common goods. Unlike public goods, common goods are non-excludable but rivalrous. Therefore, individuals cannot be excluded from their use, but consumption by one individual does reduce its availability to others.

In traditional environmental economic theory, this is the cause of market failure and justifies State intervention to avoid underproduction and depletion of natural resources (Dasgupta, 2006). Coase (1960) argues that this kind of market failure depends on the incomplete attribution of property rights on natural resources and the services they provide. Other authors argue that neither the State nor the market ensures individuals to sustain long-term, productive use of natural resource systems and so innovative collaborative governance systems are needed (Ostrom, 1990).

When it comes to NBS, assessing costs is usually quite straightforward. For example, planting a tree requires investments for the actual purchase, transport, site preparation, equipment, miscellaneous supplies, and labor costs (McPherson, 2006). However, valuing its benefits is more complicated. ES provided by trees in an urban context include climate regulation through shading, carbon sequestration, recreation, etc. (Dobbs et al., 2014). The valuation of ES benefits allows to price the impacts generated by human action on the environment, so to disclose the complexity of human-environment relationships highlighting how human decisions affect the flows and the values of ES (Mooney et al., 2005). It is important to note that the economic valuation is very unlikely to reveal the effective value of such goods or services, and an underestimation of such value is bound to occur. In particular, capturing the non-use value component of ES can be cumbersome, as it is usually measured based on the preferences of individuals who do not often have complete knowledge about the issue they are presented. The presence of biases in some valuation methodologies also affects the estimation of the economic value of a good (Graves, 2013). Measuring the monetary value of environmental goods and services still poses a problem, in particular at the urban level. The choice of the proper methodology to apply is linked to the ES to be valued (DEFRA; 2007). ES are multi-functional, that is, they provide several benefits such as improvement of air quality, climate regulation, flood risk reduction, urban heat island effect reduction, cultural and recreational services, thus helping cities to cope at the same time with the significant social, economic, and environmental challenges they face (Simpson, 1998; Majidi et al., 2019). To capture the multi-functionality of ES, it is necessary to select and adopt the appropriate valuation methodology which can fully capture the hidden values of ES. This would foster the introduction of policies and actions which protect and enhance ES though the implementation of NBS. Attaching a value to environmental goods would make it easier for their inclusion in economic choices and public decision-making processes. Eventually, this will lead to the creation of stronger conservation policies, and to the adoption of economic instruments that would result in a better safeguard of the environment, such as Payment for Ecosystem Services (PES) (Engel et al., 2008; Croci and Lucchitta, 2019).

The aim is to identify, analyze, and describe the methodologies that can be used to gauge the economic value of the ES generated by NBS at the urban level. Features and pros and cons of different valuation methodologies are assessed and a framework that highlights the linkages between specific economic valuation methodologies, ES categories, and the NBS providing these ES is created. To this purpose, a literature review of papers focused on the economic analysis of the ES provided at the urban level has been performed to detect the most frequently adopted methodologies for each category of ES. The methodologies analyzed have been categorized and associated with the ES valued. Moreover, the NBS providing the ES - e.g., urban forest, green roofs, etc. - have been considered as well. The analysis aims to contribute to i) the identification a set of case studies which carried out a monetary valuation of ES, ii) the detection the most common methodologies for the valuation of ES at the urban level and illustrating the strengths and weaknesses, iii) the creation of a framework that matches ES with valuation methodologies and iv) the identification existing gaps in valuation approaches. The chapter is structured as follows: section 2 describes the paper methodology; section 3 provides a classification of ES based on international frameworks; section 4, analyses the case studies and the valuation methodologies found in literature; discussion of results is dealt with in section 5 and finally conclusions are drawn in section 6.

3.2 Approaching the analysis of the existing methodologies

The following steps of analysis are performed: i) literature review of case studies on ES valuation at the urban level, ii) analysis of the methodologies adopted in literature (description, pros, and cons), and iii) definition of a framework linking valuation methodologies with ES at the urban level.

As first step, a literature review of case studies of ES valuation at the urban level has been performed using Scopus and Google Scholar. Research articles have been searched in English using combinations of words related to urban ES and their economic value. In particular, the following keywords have been used: first, the methodology name, followed by "ecosystem service", "urban", and "[economic] valuation". The term "[economic] valuation" has been added only when the previous search did not return any relevant result. Besides the database search of scientific literature, bibliographic references were also drawn from relevant articles and included in the present literature review. In total, the initial search yielded over 200 articles, 80 of which have been considered for inclusion in the study after screening their abstracts. Only 25 of them have been eventually selected for analysis: the ones which carry out a quantitative valuation of the economic benefits provided by ES at the urban level. On the contrary, the ones which carry out only a qualitative analysis, in absence of an economic valuation, as well as those articles gauging ES outside the urban context, have been excluded. The selected papers include 29 selected cases ranging from 1984 to 2018. The case studies collected through the literature review have been categorized based on i) the methodological category (direct market valuation, revealed preferences, and stated preferences) ii) the valuation methodology adopted, iii) the location and year of valuation, iv) the NBS that provides the ES, and v) the ES valued.

The second step includes the analysis of the methodologies used to measure the economic value generated by ES in the selected case studies. The methodologies have been analyzed and described taking into consideration three main elements: i) the description of the methodology, ii) the ES valued through each methodology, iii) the pros and the cons of the use of a methodology concerning specific ES categories. The third step capitalizes on the previous ones: pros and cons have been defined by taking into account the intrinsic properties of the valuation methodologies, the outcome of case studies on the valuation of ES, and the drivers that affect the implementation of such methodologies during the valuation process.

Finally, a framework that identifies the relations between specific economic valuation methodologies, ES categories, and the NBS providing these ES has been developed. The framework is composed of three elements: ES category, specific ES valued, and the methodology adopted for the economic valuation.

The framework has been defined capitalizing on the results obtained through the previous methodological steps.

3.3 Ecosystem services categorization

ES at the urban level contribute in several ways to human well-being. They ensure a better quality of life in cities by providing a myriad of benefits such as air and water purification, flood mitigation, noise reduction, local climate regulation, CO_2 sequestration, water and food provision, renewable energy supply, higher physical and psychological wellbeing (Simpson, 1998; Camps-Calvet et al., 2016). Several classifications of ES have been provided, including those presented by the Millennium Ecosystem Assessment (Reid et al., 2005), The Economics of Ecosystems and Biodiversity (Sukhdev et al., 2010), the Common International Classification of ES (Haines-Young and Potschin, 2012), and the Mapping and Assessment of Ecosystems and their Services – Urban ecosystems, 4th report (EC, 2016).

Figure 1 summarizes in detail the correspondence between the ES identified by the CICES and the ones considered by TEEB. The first column refers to the classification of ES made by CICES. The second column refers to the name adopted by TEEB. Finally, the last column shows the definitions of each service identified according to TEEB, except for noise reduction and regulation of water flows, the definitions of which are taken from CICES since they are absent from the TEEB classification. In order to have the full picture, the authors have included them as well. To define a complete framework of correspondence between the different classifications, ES included in the MAES Urban classification have also been highlighted (boxes outlined in black in the second column).

The ES classification according to MAES Urban is limited to only 11 out of the 21 ES presented in Figure 3. That is because MAES Urban only considers those ES which are relevant to and occur in urban ecosystems, defined as socio-ecological systems composed of green infrastructure and built infrastructure (EC, 2016). For this study, only the ES included in MEAS Urban are taken into account. According to MAES Urban, freshwater and food are the main provisioning services in cities; noise reduction, air quality regulation, moderation of extreme events, regulation of water flows, local climate regulation, climate sequestration and storage, and pollination are the main regulating ones; and finally, recreation, mental and physical health, and aesthetic appreciation and inspiration are the main cultural ones. The only ES that has been included in our study despite being left out of both MAES Urban and CICES are supporting services, namely habitats for species and maintenance of genetic diversity.

	CICES	TEEB	DEFINITION
REGULATING	Transformation of biochemical or physical inputs to ecosystems	Air quality regulation	Trees or other plants play an important role in regulating air quality by removing pollutants from the atmosphere
		Waste-water treatment	Ecosystems (e.g.: wetlands) filter effluents and break down most waste through the biological activity of microorganisms in the soil
		Noise reduction	Vegetation contributes to the impacts reduction of noise on people mitigating the harmful or stressful effect
	Regulation of physical, chemical, biological conditions	Moderation of extreme events	Ecosystems create buffers against natural disasters, thereby preventing or reducing damage from extreme weather events
		Regulation of water flows	Vegetated areas contribute to prevent and mitigate negative effects in several ways by intercepting water or through percolation
		Erosion prevention	Vegetation cover provides a vital regulating service by preventing soil erosion
		Local climate regulation	Trees and green space lower the temperature in cities whilst forests influence rainfall and water availability both locally and regionally
		Carbon sequestration and storage	Ecosystems regulate the climate by storing GHG. Trees and plants remove carbon dioxide from the atmosphere and lock it away in their tissues
		Maintenance of soil	Soil fertility is essential for plant growth and agriculture and well-functioning ecosystem supply soil with nutrients
		Pollination	Insects - but also some birds and bats - and wind pollinate plants which is essential for the development of fruits, vegetables and seeds
		Biological control	Ecosystems regulate pests and vector borne diseases that attack plants, animals and people through the activities of predators and parasites
PROVISIONING	Water	Fresh water	Ecosystems play a vital role in providing cities with drinking water, as they ensure the flow, storage and purification of water
	Biomass	Food	Ecosystems provide the conditions for growing food for human consumption
		Raw materials	Ecosystems provide a great diversity of materials for construction and fuel that are directly derived from plant species
		Medicinal resources	Biodiverse ecosystems provide many plants used as medicines as well raw materials for the pharmaceutical industry
CULTURAL	Indirect, remote, often indoor interactions with living systems that do not require presence in the environmental setting	Spiritual experience and sense of place	Customs associated to nature are important for creating a sense of belonging
	Direct, in-situ and outdoor interactions with living systems that depend on presence in the environmental setting	Aesthetic appreciation and inspiration	Environment is related throughout human history. Biodiversity, and landscapes have been the source for much of our art, culture and science
		Recreation, mental and physical health	Walking and playing sports in green space is a good form of physical exercise and helps people relax
		Tourism	Ecosystems play an important role for many kinds of tourism which in turn provides considerable economic benefits
SUPPORTING	Not present	Habitats for species	Each ecosystem provides different habitats that can be essential for a species' lifecycle
		Maintenance of genetic diversity	Genetic diversity distinguishes different breeds or races from each other, providing the basis for locally well-adapted cultivars and a gene pool for developing commercial crops and livestock

Figure 3: ES classification. elaboration adapted from CICES and TEEB.

In literature, these kinds of ES are defined as intermediate ES. Even if ES do not produce direct benefits to human well-being (Lamothe and Sutherland, 2018), through a cascade model the linkages between intermediate ES and final ES can be put in evidence by investigating their indirect contribution to human well-being (e.g., urban parks create habitat for pollinators, which in turn provide pollination, beneficial to society) (Saarikoski et al., 2015). Moreover, several studies claim that urban parks constitute biodiversity hotspots and thus provide habitat for wildlife (Nielsen et al., 2014).

Since the interaction with biodiversity is among the activities of park visitors (Palliwoda and Kowarik, 2017), the provision of habitat for species in urban contexts does contribute directly to human well-being. So habitat for species ES is deemed as a final service and not only as an intermediate one in this study. Indeed, whether ES have an intermediate or final role depends on the context (Potschin-Young et al., 2017).

3.4 Classification of methodologies for ecosystems services valuation at the urban level

3.4.1 Valuation of ecosystem services

Different approaches have been defined for the valuation of ES such as the System of Environmental-Economic Accounting Central Framework - SEEA adopted by the United Nations Statistical Commission (UN, 2012), and Mapping and Assessment of Ecosystems and their Services - MAES developed by the European Commission Joint Research Centre JRC (EC, 2013). The former hinges around asset accounts, which record both the opening and closing stock of assets and the changes over the accounting period, whereas the latter proposes a set of indicators to measure ES at the national level. A third approach has been proposed by The Economics of Ecosystem and Biodiversity (Sukhdev et al., 2010), which requires considering the Total Economic Value (TEV) generated by ES. The TEV is "the sum of the values of all service flows that natural capital generates both now and, in the future, – appropriately discounted" (Muradian et al., 2010). Hence, the TEV considers also the "hidden" components of environmental goods that markets fail to account for. The value is measured in terms of marginal changes of the natural capital stock, that is, by assessing the quality and quantity of environmental goods and services (Ozdemiroglu et al., 2006). Therefore, through a standard unit of account, the TEV can capture all elements of utility and disutility obtained from ES, taking into consideration all the services and disservices produced by nature. This framework considers both the value that humans receive when they make use of the natural capital and the value they attribute to it that does not originate from any exploitation. In particular, the TEV distinguishes between use-value and non-use value (Sukhdev et al., 2010; Ozdemiroglu et al., 2006), and both are classified in different typologies. Use-value is created when individuals interact with nature, either directly or indirectly. It includes i) Direct use-value generated when individuals in a consumptive or a non-consumptive way use nature; ii) Indirect use value indicating the benefits to individuals from ES supported by nature, without actually making use of it (Pearce, 1991; Balmford et al., 2008); iii) Option value, which is the benefit from the possibility to use a resource in the future, without any imminent intention of using it at the current time. The existence of such value is due to the uncertainty concerning future preferences and/or the availability of the good.

Non-use value is the value attributed to economic goods even if these have never been and never will be used. Non-use value consists of three components i) Altruistic value stemming from the awareness that contemporaries get to enjoy the natural environment; ii) Bequest value given by the fact environmental goods and services are preserved for future generations; iii) Existence value consisting in the satisfaction coming from the existence of the natural environment (Ozdemiroglu et al., 2006; Randall and Stoll, 1983). The TEV identifies three main approaches to valuate ES. In the first one, values are derived from the market transactions relating directly to the ES considered; in the second one, values are derived from parallel market transactions that are associated indirectly with the ES considered; in the third one, information on ES value is gauged through the creation of hypothetical markets (Sukhdev et al., 2010). Based on this, the corresponding monetary valuation methodological categories have been identified: i) Direct market valuation (market price methods, replacement cost and damage cost avoided, and production function approaches) – based on the use of data from real markets, which reflect actual preferences or costs for individuals, to estimate use value; ii) Revealed preferences (hedonic pricing and travel cost methods) - based on individual choices in existing markets linked to the use of the considered natural resource; iii) Stated preferences (contingent valuation, choice modeling, and deliberative monetary valuation) – based on the simulation of market demand for ES using surveys on hypothetical variations used for the value of use and non-use (Groot et al., 2006; King and Mazzotta, 2004; Wilson and Carpenter, 1999). Although these methodologies can be adopted at various scales, the study focuses on those that can be used at the urban level only. Through the literature review, it has been possible to determine which methodologies have been adopted so far at the scale of interest.

3.4.2 - Valuation of ecosystem services at the urban level

The choice of the methodology to apply is tightly linked to the ES to be valued. ES can vary in scale – from local, to regional, to national, to global level -, and in scope - terrestrial or marine, inland or coastal, rural or urban (Defra, 2007) -, and their presence or absence in a specific ecosystem affects the choice of the methodologies to be adopted at that level. In fact, different spatio-temporal features including habitats, geographic contexts, political and socio-economic characteristics affect how ES are provided and experienced (Pulighe et al., 2016). It is therefore necessary to understand the magnitude of the bio-physical conditions in order to properly carry out an economic valuation of the ES found at a certain scale. An ES cascade model links ecological and biophysical structures to elements of human well-being through a series of intermediate steps, thus shedding light on questions such as what the limits to the capacity of supply of ES are in different situations, and how to value the contributions that ES make to human well-being (Potschin and Haines-Young, 2011). Hence, the importance of mapping ES as a way to analyze their spatial distribution in a territory, which determinates both their supply and demand (Malinga et al., 2015; Grêt-Regamey et al., 2015). Mapping ES is also essential to make localization choices of new NBS. Indeed, mapping ES can either drive to increase the presence of NBS in areas where they are scarce, following distributional equity criteria, or to accrue the concentration of NBS in areas where the number of potential users of NBS and their willingness to pay for them is higher, following economic maximization criteria (Pulighe et al., 2016).

The analysis, by focusing on ES within cities, makes a step forward in assessing the valuation methodologies adopted at the urban level. Through the literature review, 25 papers (for a total of 29 case studies and 36 observations of ES valuations) have been found to carry out an economic valuation of ES at the urban level. In total 11 ES – 9 of which considered by MAES Urban to be found within cities, plus 2 others - have been valued in 10 Countries. Those services have been provided by 9 different NBS. The selected case studies refer to different years, ranging from 1984 to 2018. The case studies have been summarized in Table 5 and have been categorized based on the following elements: i) valuation methodology adopted, ii) location, iii) year of valuation, iv) natural resource providing the ES, and v) ES valued.

Method.	Location	Year	NBS	ES valued	Reference literature
Market price methods	Beijing	N.A.	Urban forest	Carbon storage and sequestration	Leng et al., 2004
	Lanzhou	N.A.	Urban forest	Air quality regulation	Zhang et al., 2006
	Hong Kong	N.A.	Green roof	Air quality regulation; Carbon storage and sequestration	Peng and Jim, 2015
	Boston	2015	Urban orchards	Food	Goldstein et al., 2017

Replacement cost & damage cost avoided	Stockholm	N.A.	Eurasian jays	Pollination	Hougner et al., 2006
	Sacramento	N.A.	Urban forest	Local climate regulation	Simpson, 1998
	Beijing	N.A.	Urban forest	Local climate regulation	Leng et al., 2004
	Lanzhou	N.A.	Urban forest	Air quality regulation	Zhang et al., 2006
	Southwest USA	2013	Green roofs	Local climate regulation	McRae, 2016
	Hong Kong	N.A.	Green roofs	Local climate regulation	Peng and Jim, 2015
	Rio de Janeiro	N.A.	Floodable park; green roof	Moderation of extreme events	Miguez et al., 2018
	Rome	2005	Urban forest	Air quality regulation	Capotorti et al., 2017
	Chicago	1991	Urban forest	Air quality regulation	McPherson, 1994
	Sacramento	1990	Urban forest	Air quality regulation	Scott et al., 1998
	Philadelphia	N.A.	Urban forest	Air quality regulation; CO_2 storage and sequestration	Nowak et al., 2007
	Chicago	1991	Urban forest	Local climate regulation	McPherson, 1997
	Modesto	1998	Urban forest	Local climate regulation; CO_2 and sequestration	McPherson et al. 1999
	New York	2005	Urban forest	CO_2 storage and sequestration; Regulation of water flows; Air quality regulation	Peper et al., 2007
Hedonic pricing	New York	2005	Urban forest	Aesthetic appreciation and inspiration for culture, art and design	Peper et al., 2007
	Joensuu	1984-1986	Urban forest	Aesthetic appreciation and inspiration for culture, art and design	Tyrväinen, 1997
	Portland	2007	Urban forest	Aesthetic appreciation and inspiration for culture, art and design	Donovan and Butry, 2010
Travel cost	Bulawayo	2015	Urban green spaces	Spiritual experience and sense of place	Ngulani and Shackleton, 2019

	Guiyang	2015	Urban wetland park	Recreation and mental and physical health	Wang et al., 2019
Contingent valuation	Joensuu	1995	Urban forest	Aesthetic appreciation and inspiration for culture, art and design	Tyrväinen and Väänänen, 1998
	Guangzhou	2003	Urban forest	Recreation and mental and physical health	Jim and Chen, 2006
	Beijing	2018	Green roofs	Local climate regulation	Zhang et al., 2019
Choice modelling	Hong Kong	N.A.	Green building development	Regulation of water flows; Local climate regulation; Air quality regulation	Chau et al., 2010
	South Korea	2010	Urban forest	Local climate regulation	Kim et al., 2016
	Southampton	2014	Green walls	Habitats for species	Collins et al., 2017

Table 5: ES valuation at urban level selected case studies

Based on the analysis of the cases studies, some ES have been gauged at the urban level more often compared to others: the most considered ES for valuation are air quality regulation (9 observations), local climate regulation (9 observations), carbon sequestration, and storage (5 observations), and aesthetic appreciation and inspiration for culture, art, design (4 observations). The ES fresh water and noise reduction, both among the 11 ES to be found within urban ecosystems according to MAES Urban, are not present in current literature. On the contrary, two other ES that are not included in MAES Urban classification - spiritual experience and sense of place and habitats for species - have been gauged. Table 6 summarizes the results drawn by the literature review analysis.

ES category	ES typology	N. of observations
REGULATING	Carbon storage and sequestration	5
	Air quality regulation	9
	Local climate regulation	9
	Moderation of extreme events	1
	Regulation of water flows	2
	Pollination	1
PROVISIONING	Food	1
CULTURAL	Aesthetic appreciation and inspiration for culture, art and design	4
	Spiritual experience and sense of place	1
	Recreation and mental and physical health	2

SUPPORTING	Habitat for species	1

Table 6: ES valued at the urban level

Moving on to ES valuation methodologies, not all of them are used in literature at the urban level: for example, production function approaches and deliberative monetary valuation have not been found. There are several reasons why some methodologies are not used at the urban level, such as lack of data needed to perform the valuation, impossibility to identify the impacts generated by the ES, underestimation of some ES, or because a specific methodology is used to value ES that are not present at the urban level. More in detail, Table 7 summarizes the methodologies that have been adopted in the considered papers.

Methodology	N. of observations
Market price methods	4
Replacement cost & damage cost avoided	14
Hedonic prices	3
Travel costs	2
Contingent valuation	3
Choice modelling	3

Table 7: Methodologies adopted for ES valuation at the urban level

In fact, the selection of a methodology depends on several factors, and in particular, the presence of NBS that provide specific ES at a given scale and the availability and ability to retrieve the necessary data to perform the valuation. In some cases, a specific ES is absent at the urban level and consequently some methodologies cannot be adopted. For example, production function approaches are used to determine the value of inputs affecting agriculture, forestry, and fisheries, and the ES supporting them. However, in the urban context agriculture is barely present, let alone forestry and fisheries. Another factor that determines whether a methodology is suitable to be implemented at a certain scale is the availability and the quality of data. For instance, hedonic pricing is adopted mostly in urban contexts, as it relies on house pricing data. This methodology uses the price change of a good as a benchmark; at the urban level, such good is real estate property. More in detail, the methodologies pro and cons and the possibility to adopt them at the urban level have been analyzed in detail and reported in Table 8. The table summarizes the 6 methodologies that have been used in the analyzed case studies. The structure of the methodology assessment includes: i) methodology name; ii) definition of the methodology; iii) kinds of values considered; iv) ES categories included; v) pros, and vi) cons. Pros and cons have been defined based on the strengths and weaknesses of the valuation methodology referred by authors in the case studies analyzed in the literature review.

	Meth.	Definition	Values	ES	Pros	Cons
Direct market valuation	Market Price methods (Christie et al., 2008)	"Market-price methods utilize directly observed prices and/or costs from actual markets related to the provision of an environmental good or service as a proxy to the value of those goods."	Direct and indirect use value.	Provisioning, regulating and cultural services.	Price data are easy to obtain.	The value of goods and services can be under-estimated due to market imperfections. The value of the natural resource can be underestimated, considering the inability to capture non-use values.
	Replacement cost & Damage cost avoided (Pearce and Turner, 1990)	"The replacement cost method measures the potential expenditures in replacing/restoring the function that is lost. The damage cost avoided method measures the costs that would be incurred if a specific environmental function were not present."	Direct and indirect use value.	Regulating services.	Straight forward and time- and resource- saving nature, thus allowing for an application even in countries where resources and technical skills are limited.	The methodology relies on the quality of data available, since inaccurate values can lead to a misleading appraisal of the natural resource.
Revealed preferences	Travel cost method (Ozdemiroglu et al., 2006)	"The travel cost method is a survey-based technique that uses the cost incurred by individuals travelling to and gaining access to a recreation site as a proxy for the recreational value of that site."	Use value.	Cultural services.	It allows computing recreational value of any location and is quite easy to implement.	It tends to underestimate the recreational value of the site since it only considers the time and money spent on getting there. The method cannot be applied in case of multifunctional trips, in which the visit to the site is not the only destination. It is not applicable to studies in the poorest countries, where the majority of people cannot afford to travel.

	Hedonic pricing (Pearce and Turner, 1990)	“Hedonic pricing attempts to i) identify how much of a property differential is due to a particular environmental difference between properties and ii) infer how much people are willing to pay for an improvement in the environmental quality that they face and what the social value of improvement is.”	Direct and indirect use value.	Cultural services.	It can isolate the effects of ES on land value, under the assumption that those services are fully reflected in land prices.	It relies on a large amount of high-quality data on property price.
Stated preferences	Contingent valuation (Bateman and Turner, 1993)	“Environmental evaluations are obtained by using surveys to ask people directly what they are willingness to pay or willingness to accept for a given gain or loss of a specified good.”	Use value and non-use value.	Any services.	It allows for a high degree of flexibility in the formulation of the questions, including the valuation of scenarios that are yet to happen.	Respondents’ valuation can be influenced by their prior knowledge, and by what they are told in the questionnaire. Hence, bias issues in survey design should be taken into account. It is based on hypothetical behavior.
	Choice modelling (Christie et al., 2008)	“The choice modelling technique estimates economic values by constructing a hypothetical market for the non-market environmental good.”	Use value and non-use value.	Any services.	Respondents do not have to give a price valuation of the natural resource, but just need to select their preferred policy option, thus ruling out any sort of bias related to respondents’ lack of knowledge about monetary economy.	It is more complex to analyze and to explain to the respondents, who may not look at the policy characteristics as a bundle but focus only on one attribute.

Table 8: Assessment of methodologies for ES valuation at the urban level

The analysis performed highlights the relations between valuation methodologies and ES. The same ES can be valued through a plurality of approaches: 3 methodologies in the case of provisioning services, 4 in the case of regulating services, 5 in the case of cultural services. Furthermore, it has been possible to identify the main pros and cons of each methodology. When considering the pros, they can be summed up as follows: i) easy-to-obtain data for market price methods; ii) easy-to-use methodology, hence time and resource-saving for replacement cost and damage cost avoided, and travel cost methods; iii) flexible and adaptable methodology structure for contingent valuation; iv) no previous knowledge required from respondents for choice modelling. Instead, the cons can be grouped into i) ES value underestimation for market price methods and travel cost methods; ii) high-quality data requirement for market price methods, and replacement cost and damage cost avoided methods; iii) bias problem in survey design for contingent valuation, and choice modelling.

3.5 A framework approach for the valuation of urban ecosystem services

The relationships between valuation methodologies, ES considered and NBS providing the service have been identified through the analysis. These relationships are graphically represented through a framework linking the ES considered, the methodologies adopted to value them, and the NBS that provided the specific ES valued. The methodologies are illustrated in Figure 4. The ES are divided according to the category they belong to – namely, provisioning, regulating, cultural, and supporting.

Figure 4: Framework linking NBS, ES and the methodologies used to value them (green boxes direct market valuation approach, blue boxes revealed preference approach, and light blue boxes stated preference approach)

The framework shows that direct market valuation methodologies are the most adopted in the case studies detected through the literature review. In particular, the market price methodology has been applied for the valuation of 3 different ES (food, air quality regulation and carbon sequestration and storage), while replacement costs and damage cost avoided have been applied for the valuation of 6 ES (air quality regulation, carbon sequestration and storage, moderation of extreme events, regulation of water flows, local climate regulation and pollination). The direct market valuation category is followed by stated preference category: choice modelling gauges 4 different ES (erosion prevention, regulation of water flows, local climate regulation and habitat for species), while contingent valuation 3 ES (local climate regulation, recreation and physical and mental health, aesthetic appreciation and inspiration for culture, art, and design). Finally, the least adopted category is revealed preference: travel cost method measures 2 ES (recreation and physical and mental health and spiritual experience and sense of place), while hedonic pricing only 1 (aesthetic appreciation and inspiration for culture, art, and design). In total, 7 ES are valued by direct market valuation methods, 6 by stated preference methods, and 3 by revealed preference methods. It is also possible to observe that, based on the literature review performed, a few ES have not been valued at all: out of the 11 ES identified in MAES Urban, 9 have been valued in literature so far.

The framework shows how some methodologies are used only for some categories of ES. Direct market valuation has been used to value provisioning and regulating services, revealed preferences to assess cultural services, while stated preferences has gauged regulating, cultural, and supporting services. More in detail, the ES category with the most observations is by far that of regulating services (27 out of 36 observations): air quality regulation and local climate regulation have been valued the most, with 9 valuations each, followed by carbon sequestration and storage, with 5 valuations. It is not surprising that these ES are the most studied, given their capacity to deliver positive impacts on the environmental, social, and economic dimensions at the same time (Raymond et al., 2017). For example, local climate regulation ES, which is tightly linked with urban heat island effect, generates benefits that cope with all the three challenges: through a decrease in temperature, they improve citizens well-being (social effect), diminish the impact of climate change (environmental effect), and finally, reduce households' energy expenses (economic effect). Specific methodologies have been used for the valuation of the ES for each of the following categories: provisioning, regulating, cultural and supporting. In some cases, the same ES category can be valued through different methodologies belonging to different methodological categories.

For the Provisioning category only the market price methodology has been adopted to value the provisioning of food at the urban level. In total it has been possible to detect the valuation of 1 out of 4

ES included in the provisioning category through the case study literature review, although markets exist for most provisioning services in particular those linked with water. Although, as suggested by Koetse et al. (2015) provisioning services can also be valued through contingent valuation and choice modelling valuation. For the Regulating category different methodologies have been applied: market price methods, replacement costs and damage cost avoided, choice modelling, and contingent valuation and in total it has been possible to detect the valuation of 6 out of 11 ES included in the regulating category through the case study literature review. Even in the case of regulation services other methodologies can be applied: hedonic prices, contingent valuation, and choice modelling valuation (Koetse et al., 2015; Gómez-Baggethun and Barton, 2013). For the valuation of the services under the Cultural category the methodologies adopted are travel cost method, hedonic pricing, and contingent valuation (in total it has been possible to detect the valuation of 3 out of 4 ES included in the cultural category through the case study literature review). Finally, for the Supporting category, habitat for species has been valued through the choice modelling methodology (in total it has been possible to detect the valuation of 1 out of 2 ES included in the supporting category through the case study literature review).

Besides this, as previously described, various methodologies can be used to measure the use value and non-use value of NBS, and the related ES associated. Direct use value is usually estimated through direct market valuation approaches such as market-price based, cost-based and production function approaches, which rely on data from actual markets to carry out the economic valuation (Leng, and Yang, 2014; Goldstein et al., 2017). For indirect use value, along with direct market valuation approaches, also revealed preferences (hedonic pricing and travel cost methods) (Peper et al., 2007; Ngulani et al., 2019) and stated preferences (contingent valuation and choice modelling) can be adopted (Tyrväinen and Väänänen, 1998; Collins et al., 2017). Since it is based on future scenarios that are yet to happen, option value can only be measured through stated preference methods, that is contingent valuation and choice modelling. Indeed, contingent valuation and choice modelling are the only methodologies able to value non-use values of ES. Even if these methodologies can be applied to all ES categories (Koetse et al., 2015; Gómez-Baggethun and Barton, 2013) in the case studies analyzed these methods have been used to value only 6 out of 21 ES considered.

First, the results highlight that not all the ES provided by a NBS are valuated in literature. In fact, in most of the detected case studied only one ES per each NBS considered is valued (only 3 case studies out of 25 value more than one ES). So, even if NBS are by definition multifunctional and can provide different ES at the same time, the economic valuation carried out is able to catch inly part of the generated benefits (Pulighe et al., 2016). Secondly, non-use values are often not considered in the valuation of the

ES. In fact, they can be detected through the adoption of the contingent valuation and choice modelling methodologies, which are scarcely adopted (in the case studies analyzed these methodologies have been used only 7 times out of 29). Non-use values are particularly important at the urban level as they are linked with aspects such as scenery and landscape, community identity and sense of place which significantly affect well-being in cities.

So, it can be said that the value generated by ES at the urban level is generally underestimated. The lack of considerations of the full economic value of ES generated by NBS at the urban level can incentivize undesirable conversion of ecosystems into built infrastructures, with associated loss of ES. A critical aspect refers to the difference in values estimated using different methodologies. A possibility to provide more reliable values of NBS is to use a combination of valuation models (Gómez-Baggethun and Barton, 2013; Costanza et al., 2006). Moreover, values of ES are often site-specific, as societal, and economic conditions of each context, including the characteristics of urban residents and in particular their economic status affect the values of ES following several methodologies, especially the ones based on the willingness to pay (e.g., contingent valuation) (Brzoska and Spāģe, 2020). In some case the economic valuation "can fail to reflect the plurality of values across different stakeholder groups within complex socio-ecological systems" (Haase et al., 2015). This can lead to a different attribution of values to the ES produced by a NBS based on their location. This can potentially lead to unequal distribution of NBS in cities and raise social divide issues. For example, land use planning for climate change adaptation has often been found to exacerbate socio-spatial inequalities (Pandeya, 2016) by concentrating the implementation of NBS in higher-wealth neighborhoods (Grêt-Regamey et al., 2016).

Other approaches can be adopted to assess the benefits generated by ES such as the mapping of the status of ES (Bastian et al., 2013; Kroll et al., 2012; Liu et al., 2010) helping to overcome some of the barriers and biases encountered in the economic valuation of ES. In fact, ES mapping can be used to investigate how ES values vary across space and to identify spatial areas with high or low provision and high or low demand for ES [80]. This can lead to policies targeted to reduce gaps and differences. Furthermore, mapping ES makes it possible to analyze their spatial configuration highlighting which are the inter-connections and dependencies between ES provisioning at different scales. Mapping ES can be linked to economic valuation to compare the relation between ES demand and supply (Malinga et al., 2015; Crossman et al., 2013), and to measure the economic value of the benefits derived from ES conservation and enhancement (Pulighe et al., 2016). Mapping ES and in particular presenting data at finer resolution can support the management of ES also at smaller scales and can contribute to (i) provide more relevant information for specific management interventions, (ii) facilitate the engagement of other relevant scientific disciplines (Liu et al., 2010), and iii) guide land use planning and land management at large scales, where multiple sectors, such as agriculture, urban areas, water resources, conservation and forestry intersect (Brzoska et al., 2020). This can help to consider the urban-rural area interactions that are essential to ensure the flow of ES. Even if most of the ES mapping studies are focused on a wider scale, studies in urban areas are increasing. In fact, one of the main barriers encountered in valuation is the lack of bio-physical data, so the creation of a dataset on the state of ES over time based on mapping of ES can support the application of several economic valuation methodologies.

Overall, the economic valuation of ES should be further developed and experimented at the urban level also with the support of other approaches and the interaction with other disciplines. In fact, economic valuation can contribute to improved urban planning and management of NBS by informing decisions makers about the full social cost and benefits provided by ES, so leading the more efficient public choices and increase of social wellbeing.

4 Policy instruments for the protection of nature at the urban scale

Abstract

The chapter highlights the potential of nature in cities in mitigating and adapting to climate change. The concept of Nature-based solution (NBS) has gained more and more attention in relation to its capacity to provide a wide array of ecosystem services (ES) in different contexts, including urban areas. In fact, NBS can address several urban challenges, as ecosystems in healthy condition provide a variety of functions and deliver multiple services, so contributing to climate commitments and more in general to social welfare.

Targeted policies and instruments can be adopted by local governments to foster the implementation of NBS in urban areas to enhance resilience and mitigate emissions. Payments for Ecosystem Services (PES) can protect and enhance natural assets connecting users and providers of ES through voluntary or regulated transaction schemes. Specific urban PES case studies are analyzed considering the stakeholders engaged, the revenues generated, the ES generated and the transaction mechanisms. Results show that PES have proven to be effective in investing and managing urban NBS. The complexity of urban environments and the interactions between many ES requires to adequately value the benefits generated.

4.1 Natural capital and climate change

4.1.1 The contribution of natural capital and ecosystem services to climate mitigation and adaptation

The variety of services described in the previous chapters contribute directly (e.g., food production, etc.) or indirectly (e.g., pollination) to human well-being through a cascade model described in Figure 5. Natural capital provides in fact several functions through ES, so benefitting society and generating social value. The consideration of the values generated by ES and the losses connected to their degradation is essential to make policy and production/consumption choices in coherence with sustainable development (Dasgupta, 2021).

Services provided by ecosystem generate, among others, benefits that can influence the stability of the climate, mitigating and adapting the impacts generated by climate change (Turner, 2009; Epple and Dunning, 2014, Locatelli, 2016, IPCC, 2019). Ecosystems can mitigate climate change since they act as carbon sinks through the process of CO_2 capture and storage. At the same time, they contribute to adaptation, providing services that reduce the impacts of extreme events (e.g., floods, storms, etc.) and contribute to local climate regulation. The idea that natural ecosystems can help us fight both the drivers and impacts of climate change has been gaining traction over the past few years, including in the IPCC Special Report (IPCC Special Report on Global Warming of 1.5 °C (IPCC, 2018).

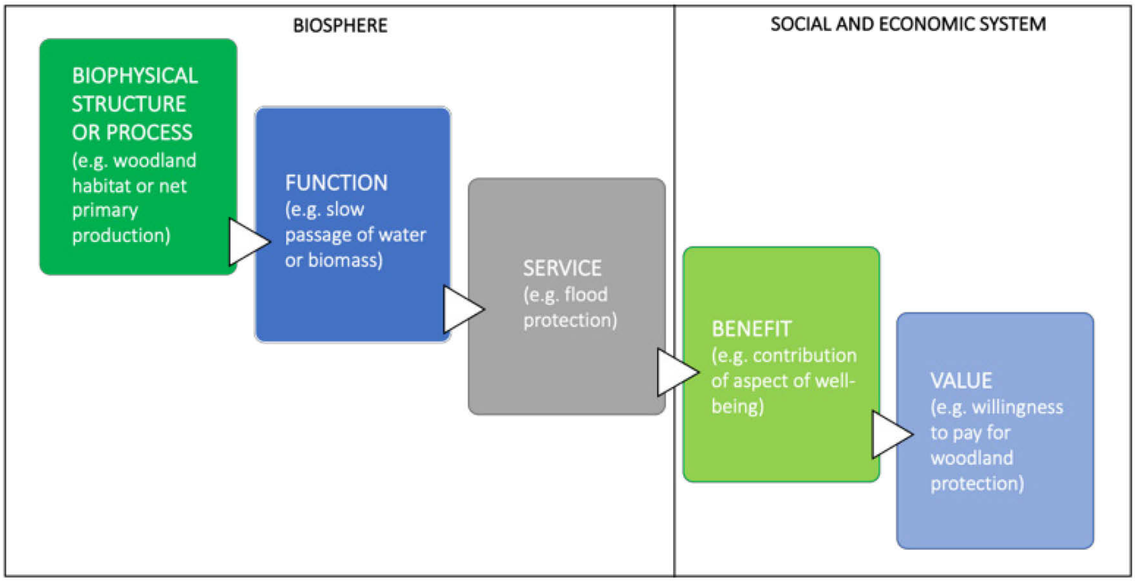


Figure 5: ES cascade model (authors elaboration from Potschin and Haines-Young, 2016)

The IPCC Climate Change and Land Report (IPCC, 2019) emphasizes that the mitigation potential from terrestrial ecosystems comes from restoration and management of forests. The report states a mitigation potential range of 0.4–5.8 Gt CO_2 yr−1 from avoided deforestation and land degradation, as well as a carbon sequestration potential of 0.5–10.1 Gt CO_2 yr−1 in vegetation and soils from afforestation/reforestation (IPCC, 2019). More recently, Harris et al. (Harris et al., 2021) found that the world's forests sequestered about twice as much carbon dioxide as they emitted between 2001 and 2019. In other words, forests provide a "carbon sink" that absorbs a net 7.6 billion metric tonnes of CO_2 per year[3].

At the same time, ecosystems reduce disaster risks and vulnerability of people and infrastructures and increase territorial resilience. The concept of resilience is not new. Holling et al., (1973) described it as the capacity of complex and dynamic ecosystems' ability to absorb shocks or disturbances, like forest fires or hurricanes, and continue to function (Alexander 2013; Folke et al. 2010; Holling 1973). More recently the term resilience has been used for natural ecosystems to describe the "ability of a social or ecological system to maintain basic structural and functional characteristics over time despite external pressures. This use of the term acknowledges the fact that all systems undergo continual change, both as a result of internal processes and in response to external factors" (Epple and Dunning, 2014). The ability of ecosystems to mitigate shocks and to ensure the functioning of social-economic systems can be defined as their insurance value (Green et al., 2016), meaning that ecosystems allow to reduce and buffer against negative impacts, such as climate change, or extreme events (Gómez-Baggethun and Barton 2013; Bateman et al., 2014). An ecosystem-based adaptation approach aims to "use activities such as the sustainable management, conservation and restoration of ecosystems as part of an overall strategy to adapt or mitigate climate change effects".

In the last decade, a growing consensus has emerged on the importance of ES and their integration in the management of natural resources and territorial planning (Daily et al., 2009; de Groot et al., 2010; Tratalos et al., 2007). In particular, NBS can play a relevant role in enhancing natural capital at different scales and in providing several ES, including climate change mitigation and adaptation. Three main types of NBS can be individuated (Eggermont et al., 2015):

- solutions that involve making better use of existing natural or protected ecosystems;
- solutions based on developing sustainable management protocols and procedures for managed or restored ecosystems;
- solutions that involve creating new ecosystems.

The first typology is aimed to maintain or improve the delivery of some ES through small interventions on ecosystems (e.g., protection of mangrove systems, definition of protected natural areas, etc.). The second typology consists in the design and adoption of approaches aimed to "develop sustainable and

[3] The study estimates that global forests were a net carbon sink of $-7.6 \pm 49\,GtCO_2e\,yr^{-1}$, reflecting a balance between gross carbon removals ($-15.6 \pm 49\,GtCO_2e\,yr^{-1}$) and gross emissions from deforestation and other disturbances ($8.1 \pm 2.5\,GtCO_2e\,yr^{-1}$).

multi- functional ecosystems and landscapes which improve the delivery of selected ES compared to what would be obtained with a more conventional intervention" (e.g., agricultural diversity to improve multifunctionality, increase tree species genetic diversity, etc.). The third typology includes interventions aimed to reinforce or create new ecosystems and it is linked with the concept of green and blue infrastructures (e.g., green roofs and walls, sustainable urban drainage systems, etc.).

The idea of NBS is being used to repackage policy debates on biodiversity conservation, climate change (adaptation and mitigation), and sustainable use of natural resources, air pollution together with public health, social justice, and green economic opportunities. By enhancing and reinforcing ES action, NBS can range from measures to prevent flooding (such as natural water retention measures, dyke relocation, re-naturing rivers, buffering areas, restoration of wetlands, woodlands, floodplain, re-meandering, de-poldering, set back of estuarine defenses, maintaining dunes, beaches and salt marshes) to responding to heat island effects in cities (through multifunctional green public spaces) and droughts and erosion in rural areas (through sustainable agricultural practices and irrigation systems, reforestation, rainfall water management, torrents and river management) (EC, 2015).

4.1.2 The role of NBS in the Paris Agreement

The importance of natural capital and ES has been highlighted by several international initiatives. In 1994, the United Nations Convention to Combat Desertification (UNCCD) has been established with the aim to develop policies and measures to fight desertification and protect ecosystems. The new UNCCD 2018-2030 Strategic Framework is a comprehensive global commitment to achieve land degradation neutrality in order to restore the productivity of vast expanses of degraded land. In October 2010, the Strategic Plan for Biodiversity for the 2011-2020 has been adopted during the COP10 of the Convention on Biological Diversity. The Plan provides an overarching framework on biodiversity for all Countries and all stakeholders engaged in biodiversity management and policy development.

In September 2015, the UN approved the Agenda 2030 and the 17 sustainable development goals (SDGs) that aim to achieve sustainability at all levels and sectors (Cumming et al., 2017; Wood et al., 2018; Gomez Martin et al., 2020). The preservation and enhancement of natural capital are included in several goals (SDG12 – Responsible consumption and production, SDG13 – Climate change, SDG15 – Life on land) also affecting the urban context. Furthermore, SDG 11 is dedicated to the sustainable development of urban areas, and it addresses several aspects also related to the potential of ecosystems for the quality of life and well-being improvement in cities including their importance in mitigating and adapting to climate change. In October 2016, UN-Habitat presented the New Urban Agenda that promotes a new model of urban development to integrate environmental protection, sustainable economic growth, and social equity. One of the Urban Agenda objectives is to integrate disaster risk reduction and climate change adaptation and mitigation considerations and measures into resilience-based and climate-effective design of spaces, buildings and construction, services, and infrastructure, and NBS.

In December 2015, at COP21 in Paris, Parties to the UNFCCC (United Nations Framework Convention on Climate Change) decided to strengthen the global response to the threat of climate change through the adoption of the Paris Agreement (PA). The PA aims to catalyze action and investment to limit the increase of the global average temperature to 2°C, or preferably to 1.5°C, above pre-industrial levels by the end of the century. Countries that signed the PA commit to undertake and communicate their efforts in Nationally Determined Contribution (NDCs), contributing to the achievement of the PA objectives. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. All Parties must communicate their NDCs to the UNFCCC, to be revised every five years and demonstrate increased ambition over time. Additionally, Countries must define and communicate long-term strategies (LTS) that describe phase out pathways to low carbon transition. So, the NDCs can be defined as "stepping-stones" to achieve mitigation and adaptation targets and the LTS as the instruments that provides a country with direction and vision for increasing ambition in future. In this context ecosystems protection and enhancement play a relevant role in national strategies and commitments to lead to carbon neutrality thanks to their capacity to remove carbon dioxide from the atmosphere and to store it. Different mitigation strategies are coherent with a pathway that limits global warming to 1.5°C. All pathways use, in different measure, Carbon Dioxide Removal (CDR), and Bioenergy with Carbon Capture and Storage (BECCS) and removals in the Agriculture, Forestry and Other Land Use (AFOLU) sector (IPCC, 2019).

The PA explicitly recognizes "the importance of the conservation and enhancement, as appropriate, of sinks and reservoirs of the GHG referred to in the Convention" in light of the significance of ecosystems for climate change mitigation and adaptation, as well as the societal value they provide. Various Articles include direct reference to ecosystems. The table below (Table 9) summarizes the PA articles that make a clear reference to the importance of ecosystems for mitigation and adaptation to climate change.

Preamble	Recognizing the importance of the conservation and enhancement, as appropriate, of sinks and reservoirs of the GHG referred to in the Convention. Noting the importance of ensuring the integrity of all ecosystems, including oceans, and the protection of biodiversity.

Article 5	5.1 Parties should take action to conserve and enhance, as appropriate, sinks and reservoirs of GHG as referred to in Article 4, paragraph 1(d), of the Convention, including forests. 5.2 Parties are encouraged to take action to implement and support, including through results-based payments, the existing framework as set out in related guidance and decisions already agreed under the Convention for: policy approaches and positive incentives for activities relating to reducing emissions from deforestation and forest degradation, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries; and alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, while reaffirming the importance of incentivizing, as appropriate, non-carbon benefits associated with such approaches.
Article 7	7.1 Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional, and international dimensions, and that it is a key component of and contributes to the long-term global response to climate change to protect people, livelihoods and ecosystems, taking into account the urgent and immediate needs of those developing country Parties that are particularly vulnerable to the adverse effects of climate change. 7.9 Each Party shall, as appropriate, engage in adaptation planning processes and the implementation of actions, including the development or enhancement of relevant plans, policies and/or contributions, which may include: (c) The assessment of climate change impacts and vulnerability, with a view to formulating nationally determined prioritized actions, considering vulnerable people, places, and ecosystems. And (e) building the resilience of socioeconomic and ecological systems, including through economic diversification and sustainable management of natural resources.
Article 8	8.4 Accordingly, areas of cooperation and facilitation to enhance understanding, action and support may include: (h) Resilience of communities, livelihoods, and ecosystems.

Table 9: Ecosystem services in the Paris Agreement (authors elaboration)

Several NDCs include NBS as measures to achieve the targets defined by the PA. More in detail, 66% of the PA signatories commit to restoring or protecting ecosystems in their NDCs (Nature-based solutions Initiative, 2021[4]). Out of 168 NDCs, 104 include commitments to working with natural ecosystems in their adaptation plans, while an additional 27 describe NBS actions in their mitigation plans (76 nations include NBS actions in both their adaptation and mitigation plans). NBS are particularly present in the adaptation plans of low or lower-middle income tropical and subtropical nations. Seddon et al (2019) carried out an analysis of the NDCs presented by the different countries to understand the role of NBS in the achievement of the mitigation and adaptation targets at the national level. NDCs analyzed include actions aimed to improve the management and restoration of terrestrial forests and to fight deforestation. Instead, the percentage of NBS that consider grasslands, drylands, coastal and/or marine ecosystems and other wetlands is quite low in the NDCs. NBS are considered to have an important role

[4] https://www.naturebasedsolutionsinitiative.org

in the NDCs, but only around 17% of NDCs with current or planned actions involving NBS for adaptation are associated to evidence-based targets. Actions related to the forest sector are widespread into the NDCs (over 70% of NDCs contain action aimed to enhance and protect world forests), but only the 20% of these NDCs include quantifiable targets. Furthermore, only a small part of the NDCs includes consideration about synergies between mitigation and adaptation actions. More in detail, only 17 countries aim to address adaptation and mitigation together or have sections in the adaptation components of their NDCs that explicitly highlight the mitigation benefits of adaptation action.

Although the benefits generated by NBS for mitigation and adaptation to climate change are now recognized, the results reported above show that there is still a need to improve the integration of these measures within national strategies. The role of national policies appears to be fundamental for the protection and strengthening of ecosystems, but at the same time local authorities can catalyze the changes defied at national level. It is increasingly evident that action at the subnational level (regional and municipal) plays a crucial role in following up and implement the strategies and objectives set at the national or international level. The governance of climate change is a complex and multilevel process. Consequently, it can be said that the traditional analytical divisions between international and domestic politics, between local, national, and global scale and between state and non-state actors are no longer sufficient (Betsill and Bulkeley, 2006). Indeed, global environmental policies are not only a matter of international negotiation and development of national policies, but also take place at the local level (Widerberg and Pattberg, 2015). Furthermore, the Paris Rulebook reaffirms the key role that a broad range of stakeholders, including regions, cities, play in ensuring action for climate. It also outlines those specific projects, that may contribute to mitigation or adaptation should be included in the NDCs, which may cover, but are not limited to, key sectors, such as energy, resources, water resources, coastal resources, human settlements and urban planning, agriculture, and forestry.

4.2 The assessment of NBS contribution for climate change mitigation and adaptation

Recent estimates quantify a relevant potential of cities to contribute to global decarbonization, with a reduction potential of 17.3 $GtCO_2eq$ in 2050 (Coalition for urban transition, 2019). Several voluntary initiatives have been launched to involve local governments in mitigation and more recently in adaptation – such as the Covenant of Mayors by the European Commission and 100 Resilience Cities by the Rockefeller Foundation. Local governments are increasingly being recognized as having high potential to drive climate change mitigation and adaptation actions thanks to their knowledge of the territory, their responsibilities, and powers. Mitigation and adaptation options vary by city characteristics and development level. Major options available for rapidly developing cities include shaping their urbanization and infrastructure development paths. These strategies affect urban GHG emissions by shaping the individual and collective behaviors (Croci et al., 2017). The Figure 6 show the plethora of action cities can adopt to achieve climate change and mitigation targets, NBS give a strong contribution for both mitigation and adaptation targets.

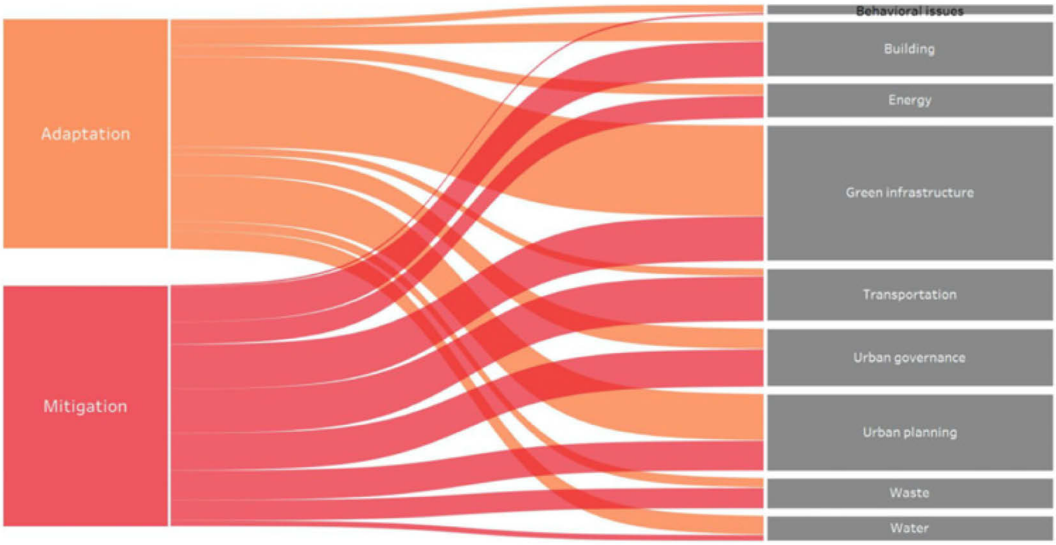


Figure 6: Major categories of urban actions and their relationship with mitigation and adaptation (Sharifi, 2020)

While the role of natural capital has been investigated by scholars and policy makers with reference to the global, regional, and national scales since several decades, only recently its relevance at the urban scale has been analyzed. NBS can address several urban challenges, thanks to their multi-functionality, as, ecosystems in healthy condition provide a variety of functions and deliver multiple services. Main functions at the urban scale regard: improving the environment, making cities more attractive, enhancing human well-being, restoring degraded ecosystems, developing climate change adaptation and mitigation, improving disaster risk management and resilience (EC, 2015). In fact, functioning ecosystems allow cities to build adaptive capacities and cope with several urban challenges, providing several ES, including reduction of local air pollution, microclimatic regulation (heat island phenomenon reduction and temperature increase due to climate change), direct health benefits, such as a lower prevalence of asthma in early childhood), mortality reduction, and general health improvements, flood risk reduction, quality of life improvement, social inclusion, safety and cultural benefits (Croci and Lucchitta, 2019). Several studies (Escobedo and Nowak, 2008; Churkina, 2017) confirm that urban vegetation has positive effects on air quality by eliminating polluting determinants, altering the urban microclimate, and reducing temperatures through the produced shadow, the evapotranspiration processes, attenuating the winds and decreasing the energy consumption of the buildings, also generating a reduction in CO_2 emissions from power plants. These services are generated by a diverse set of land uses, including parks, waterways, avenues, gardens and courtyards, docks, municipalities, green roofs, and facades, etc. Furthermore, the dependence of cities on the surrounding landscape and its biodiversity is essential to support the production, enhancement, and maintenance of ES and to guarantee the resilience of urban systems as a whole. NBS can generate positive impacts on environmental, economic, and social dimensions, addressing four principal goals at the urban level:

1. stimulate economic growth as well as improving the environment, making cities more attractive, and enhancing human well-being.
2. improve the resilience of ecosystems, enabling them to deliver vital ecosystem services and to meet other societal challenges.
3. provide more resilient responses and enhance the storage of carbon.
4. offer synergies in reducing multiple risks.

NBS have the ability to reinforce ES at urban level creating or enhancing the connections between built and natural areas. When considering NBS in relation to ES, Dorst et al. (2019) describe them as able to address resource shortages (e.g., water shortages), floods and heat risks and ecosystem degradation caused by processes of urbanization and climate change. On the other hand, Kabisch et al. (2016) focus on the maintenance, enhancement, and restoration of biodiversity. Ecological systems provide a wide range of functions which benefit urban environments. NBS has emerged as a concept, or umbrella term, for ecosystem-based approaches to address the societal challenges of climate change, natural disasters, food and water security, human health and well-being, and economic and social development (Cohen-Shacham et al., 2016; EC, 2015). The classification of urban ES has been deeply investigated (Bolund and Hunhammar 1999; TEEB 2011; Gómez-Baggethun et al. 2013; Sieber and Pons 2015). In particular, all the services provided by ecosystems that are linked with mitigation and adaptation to climate change are included in the regulatory category. The following ES are fundamental for mitigation purposes: air quality regulation, local climate regulations, and carbon sequestration and storage. Instead, the following ES are relevant for adaptation purposes: waste-water treatment, moderation of extreme events, regulation of water flows, and local climate regulation. Figure 7 summarizes the list of the ES provided by NBS at the urban scale that are able to contribute to the achievement of climate goals at the local level. Ecosystem services framed in black are those that have a positive impact for mitigation and adaptation to climate change.

Figure 7: Regulation services at the urban scale (author's elaboration from Croci et al., 2021)

The mitigation potential of NBS is widely recognized in literature, in particular with reference to the carbon sequestration potential of green areas and trees, the regulation of urban temperature and the decrease of the urban heat island effect (UHI), and the reduction of buildings energy demand. Several authors analyzed the capacity of urban greening to capture and store CO_2 with a specific focus on urban forestry and trees. Table 10 summarizes the CO_2 sequestration capacity of urban trees in different cities.

City	**CO_2 sequestration**
Barcelona, Spain	0,54 t/ha/year (Barò et al., 2014)
Syracuse, USA	0,54 t/ha/year (Nowak and Crane, 2002)
Baltimore, USA	0,52 t/ha/year (Nowak and Crane, 2002)
Averaged over 28 cities and 6 States in the United States	0.28kg C/m^2/year (av. gross CO_2 sequestration rate per unit tree cover) (Nowak et al., 2013)
Averaged over 5 EU cities	2,43 t/ha/year (Naturvation, 2019)

Table 10: Urban forest CO_2 sequestration capacity (authors elaboration from EC, 2020)

Other urban green spaces are valuable for storing and sequestering carbon (Barò et al., 2014). The measurement of the CO_2 storage capacity of different land uses has been performed in several studies. The InVEST (Integrated Valuation of Environmental Services and Trade-offs) uses maps of land use along with stocks in four carbon pools to estimate the amount of carbon currently stored in a landscape or the amount of carbon sequestered over time. Results show that parks and (semi) natural urban green areas can store 32,6 kg CO_2/m^2, green roofs and walls 5,4 kg CO_2/m^2, allotments and community gardens 27,3 kg CO_2/m^2 and green areas for water management 12,5 kg CO_2/m^2. Another significant impact generated by NBS is the regulation of urban climate thanks to their capacity to mitigate urban temperature. Seddon et al (2020), found that the temperature of urban green spaces in daytime is on average 0.94°C cooler than in other urban spaces. Furthermore, Elmqvist et al. (2016) showed that a 10% increase in tree canopy cover may result in a 3 - 4.8 °C decrease in ambient temperature. Finally, NBS can be used directly to reduce energy demand in the built environment. In. fact, green walls and roofs can provide an effective means through which to reduce energy demand. Besir and Cuce (2018) found green roofs can reduce the heat penetration by up to 80%, reducing energy consumption by 2 – 17 %., while green walls energy demand reduction potential is estimated in the range 10 – 30 % (Besir and Cuce, 2018).

At the same time NBS can improve the adaptation potential in urban areas. This is particularly true for flood mitigation potential (e.g., rain gardens, bioswales, SUDS). Green roofs show large effects on annual stormwater runoff and on peak flows (Stovin et al. 2013; Keesstra et al., 2018). Bioswales and biofilters are alternative solutions to handle stormwater on ground if space is available. Functionally, these systems also have a potential for infiltration and evapotranspiration (Daly et al., 2012). Chapman and Horner (2010) report that a street-side bioretention facility in Washington can achieve 26 –52 % of runoff retention for certain rainfall events. Finally, Holden et al. (2007) highlight the importance of wetlands in the attenuation of flood events, in particular the observations have shown that vegetation cover can affect the velocity of water flowing across wetlands and hence flood generation. It must be said that - as highlighted by Emilsson and Ode Sang (, 2017) - urban NBS have little impact on large-scale catastrophic rainfalls. Thus, it is necessary working at different scales to define a wider adaptation strategy to reduce extreme events.

The literature review results on the impacts generated by different NBS at the urban scale for climate change mitigation and adaptation have been summarized in Table 11. Ecosystem services provided by NBS that generate positive impacts for mitigation and adaptation to climate change they are identified by an asterisk.

Beyond climate, NBS generate benefits that can contribute to achieve a wider set of goals contributing to environmental, economic, and social sustainability, especially at the local and regional levels. Furthermore, “the many advantages of NBS are often not immediately apparent, but instead accumulate over a longer period” (Naumann et al., 2014).

	Air quality regulation*	Waste-water treatment*	Noise reduction	Moderation of extreme events*	Regulation of water flows*	Erosion prevention	Local climate regulation *	Carbon sequestration and storage*
Green roofs								
Green walls								
Urban trees								
Urban green areas								
SUDS								
Wetlands								
Bioretentions basin								

Table 11: Regulation services at the urban scale (ES generating positive impacts on climate change mitigation and adaptation are marked with an asterisk)

4.3 Policy instruments to enhance urban NBS

4.3.1 Payment for ecosystem services

The concept of value linked to NBS is multi-faceted since it comprises different types of benefits. These benefits are perceived by different stakeholders, and they are delivered over different periods of time. Therefore, the assessment and evaluation of the value created by NBS is a complex task.

So, it is difficult to establish commonly adopted methods to precisely allocate the share of investment contributions of each stakeholder according to the benefits generated by the measure implemented. The benefits provided by NBS include i) the reduction of environmental harmful externalities (e.g.: CO_2 capture and storage, reduction of air pollutants), ii) the reduction of climate related risks (e.g.: flood risk reduction, moderation of extreme events) and iii) the provision of social benefits (e.g.: improvement of health, job creation, urban regeneration).

The capacity to catch the values generated by NBS through market transactions or policy instruments is defined as "value capture". Based on the economic theory on the classification of goods (Ostrom, 1990) four categories of goods can be individuated: private goods, public goods, tool goods and common pool resources[5]. NBS often show characteristics of public goods or common pool resources and therefore

[5] A private good is excludable, i.e., its owners can exercise private property rights, preventing those who have not paid for it from using the good or consuming its benefits; and rivalrous, i.e. consumption by one necessarily prevents that of another. A public good is non-excludable, non-rivalrous, and open to all in its consumption (clean air, soil water storage that yields flood control, and beautiful views over a landscape). A toll good is excludable,

can generate market failures, since the price mechanism does not guarantee an optimal level of their production and allocation. To correct market failures in presence of public goods a solution can be the intervention of the state in their production and management, through fiscal instruments (general or purpose ones). In the case of common pool resources, a solution can be the introduction of governance tools to regulate its use through an institutional framework. In this way the public sector can introduce policy instruments aimed to internalize positive externalities, catching the value generated by NBS which are not reflected by market prices.

The enhancement of ES depends also on the capacity of local governments to introduce instruments to protect and facilitate the implementation and management of NBS in cities (Naeem et al., 2015). In particular, payments for ecosystem services (PES) which aim to stimulate the production of positive externalities, transforming them into goods that can be bought and sold on a market. In other words, PES are tools that aim to change behaviors having negative impacts on ecosystems by introducing the economic value of ecosystem services in decision-making. A PES can be defined as a voluntary transaction between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services (Wunder, 2015). The concept of PES is quite new, and it is based on the idea that the beneficiary of an ES should reward the owner of the natural resource generating the service to ensure its maintenance or to improve its conditions. Wunder (2005) defines a PES as "a voluntary transaction where a well-defined service (or a land-use likely to secure that service) is being "bought" by a (minimum one) ES buyer from a (minimum one) ES provider if and only if the ES provider secures ES provision (conditionality)". Such a definition has been revised by the author himself after receiving a series of criticisms, mainly concerning the market-linked nature of PES (Tacconi, 2012; Muradian et al., 2013). Hence, Wunder re-defined PES as "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services" (Wunder, 2015). PES schemes allow service buyers to pay for the safeguard of an environmental service on which they are reliant, hence preventing the risk it becomes scarce, and to compensate for the negative externalities caused by production or consumption activities to the society (UNEP, 2009). In this way, it is possible to change those behaviors which harm ecosystems (Rojas and Aylward, 2003).

Economic, institutional, and cultural conditions are necessary for the realization of a PES scheme. The economic condition implies that the users' maximum willingness to pay corresponds to or is higher than

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but non-rivalrous (such as access to private parks). A common pool resource is rival and non-excludable (such as fish stocks in an ocean).

the providers' minimum willingness to accept the compensation. If this did not occur, then the service provided would be assessed less than the estimated cost provision landowners are facing for deviating from their land-use plan. Therefore, benefits derived from preserving natural resources via PES need to exceed the costs of incremental service provision. The cultural condition implies that the service users are willing to pay for the ES, and the providers must be willing to change their own management habits of the natural resource that produces a specific ES. The institutional condition implies that a third party – such as external intermediaries or facilitators – can create trust between actors to ensure the correct PES scheme execution. So, a PES scheme requires complex social interactions over time: if all parties were to act independently in perfectly competitive markets, transaction costs would be enormous given the number of different actors to be involved, and no PES would ever take place. Most importantly, however, PES cannot function without tenure clarity and security: if such well-defined stewardship does not pre-exist, then local land users will lack the crucial right to exclude third-party access, making them unreliable service providers with insufficient control over service delivery (Salzman et al., 2019).

More recently the voluntary character of a PES has been challenged, considering the option of a stronger role of public entities, which can go beyond the role of intermediary or facilitator and act as a regulator. Salzman et al. (2019) individuated three typologies of PES. The first one is called *User-financed PES*. Users of ES compensate landowners to maintain or enhance the delivery of ES. In this case the users (public or private) are direct beneficiaries of ES protection. The second typology is the *Government-financed PES*, public entities on behalf of users compensate landowners to maintain or enhance ES delivery. The last category of PES is the *Compliance PES* in which parties facing regulatory obligations compensate other parties for activities to maintain or enhance comparable ES or goods in exchange for a standardized credit or offset that satisfies their mitigation requirements (water quality trading, wetlands mitigation banking and emissions trading scheme for GHG).

4.3.2 Case studies of PES application at the urban scale

PES diffused in several countries over time and gained attention in climate policy. In 2008 the UN introduced the REDD+ program which aims to protect forest in developing countries through the definition of PES schemes in developing countries. However, PES have been implemented mainly on large scales. Through an extensive literature review[6], five case studied of urban PES schemes have been

[6] The review has been performed by using Scopus. The keywords used for the research are urban, PES, stewardship and ecosystems voluntary agreements. 63 papers have been analyzed, but only few of them are focused on the implementation of PES schemes at the urban scale. The case studies have been selected based on two criteria: i) involvement of local stakeholders in the PES scheme and ii) ES sold generate direct impacts at the urban scale.

selected: Victoria Business Improvement District (BID) case study (London), Adopt a green spot case study (Milan), Catskill watershed case study (New York), the Payments for Watershed Services – PSHA case study (Mexico City) and the Wimbledon and Putney Common Levy case study (London). The case studies have been analyzed considering the scheme mechanisms, the stakeholders engaged the revenues generated, the ES provided through the scheme and the other ES generated. The case studies have been summarized in Table 12 to compare their structures and peculiarities.

Victoria BID (London, UK)	**Description:**the Victoria BID was established in 2010 after a successful ballot of all the businesses liable to pay the business rate levy in the area. A BID is a defined area in which a levy is voluntary charged on all business rate payers in addition to the business rates bill. This levy is used to develop projects which will benefit businesses in the local area. There is no limit on what projects or services can be provided, the only requirement is that it should be in addition to services provided by local authorities. The BID is managed by a Business Improvement District body in partnership with the local authority. In Victoria BID the taxes revenues have been used for the implementation of some NBS, such as trees plantation, green wall realization, new park realization. **PES typology:** user-financed PES **ES seller:** municipality **ES buyer:** local business and the BID **ES bought:** cultural **Revenues:** /NA **Other ES provided:** provisioning and regulation
Adopt a green spot (Milan, IT)	**Description:** Milan Municipality in 2005 launched the “Adopt a green spot” initiative. This initiative foresees the engagement of various stakeholders in the management of urban green areas. Citizens, NGOs, private companies, universities can, directly or indirectly, provide for the maintenance of green areas within the city through standardized voluntary agreements designed by the Municipality. A special municipal office was established to promote, manage, and monitor the initiative. The duration of the contracts varies from 3 to 5 years based on the agreement typology. The areas under the initiative are flowerbeds, urban parks and gardens, recreational areas, roundabouts, tree lines and trees. Through the sponsorship agreement, the private partner (the contractor) provides the Municipality an economic contribution to the project implementation and maintenance. Through a collaboration agreement the direct implementation of the green area project is taken on by the private partner who also takes care of the maintenance costs during the duration of the agreement. In both cases, the municipality gives public recognition to the contractor through a plate placed in the green area. **PES typology:** user-financed PES **ES seller:** municipality **ES buyer:** Various (citizens, universities, firms, NGOs, condominiums) **ES bought:** cultural **Revenues:** 2,6 million euros **Other ES provided:** provisioning and regulation

Catskill watershed (New York, USA)	**Description:** the agreement was signed, in 1990, between the NYC municipal company for water services provision and forest owners of the catchment basin. Owners are committed to manage forests in accordance with a program that includes forest management practices which have positive effects on the qualitative and quantitative consistency of water runoff. Compensation for ES performed is paid through surtax on water tariff, paid by end users. The City spent 1.5 billion $ in watershed protection projects against 6 billion $ to build the plant plus another 250 million $ per year for maintenance. **PES typology:** compliance PES **ES seller:** landowners **ES buyer:** municipality and citizens **ES bought:** provisioning **Revenues:** 1,3 billion euros **Other ES provided:** regulation
PSAH (Mexico City, MX)	**Description:** Mexico's National Forestry Commission manages the PSAH program. The program allows landowners to propose projects aimed to better manage the forests to enhance and protect the ecosystems provided. PSAH participants' activities should preferably focus on forest cover conservation aimed at recharging aquifers and halting soil erosion. Operational rules select the applications best fitting such purposes by prioritizing lands that fall in officially declared overexploited Forest and Soil National Inventory. Each year the National Forestry Commission select the projects that will be financed, the National PSAH funding comes from an increase in the water tariff. Furthermore, the National Forestry Commission is in charge to check that the projects are carried out following the standards and criteria previously defined. **PES typology:** compliance PES **ES seller:** farmers **ES buyer:** National Forestry Commission and citizens **ES bought:** provisioning and regulation **Revenues:** 15,5 million euros **Other ES provided:** cultural
Commons Levy (London, UK)	**Description:** Wimbledon and Putney commons contain about one million trees and provide open green space to the local community. The Wimbledon and Putney Commons Act 1871 lays a duty on the Conservators to *preserve the "forest functions and to ensure its public and local use, for the purposes of exercise and recreation"*. To fulfil these duties the Conservators, have access to a budget of around £1.3 million, two thirds of which comes from the Commons Levy, which is paid by council tax payers in the Levy area. The Common Levy tax has been established on order to maintain the forest close to Wimbledon and Putney. The Levy can be considered a PES arrangement as all those who choose to live within 3⁄4 of a mile of the commons and therefore benefit from their proximity to numerous recreational and cultural services, have to pay a tax for the maintenance of the forest. **PES typology:** compliance PES **ES seller:** municipality **ES buyer:** citizens **ES bought:** cultural **Revenues:** 1 million euro **Other ES provided:** provisioning and regulation

Table 12: PES case studies description (authors elaboration)

To better analyze the different structures of the PES considered, four main elements that characterize the PES schemes have been evidenced: i) ES buyers; ii) ES sellers; iii) the payment defined for the provision of the ES and iv) the benefits generated by the ES. Figure 8 summarizes the analysis of the PES scheme structures.

Figure 8: A) Victoria BID PES scheme; B) Adopt a green spot PES scheme; C) Catskill watershed PES scheme; D) PSAH program PES scheme; E) Commons Levy scheme (authors elaboration)

The case studies presented show specific characteristics regarding the voluntary or mandatory nature of the agreement. The Catskill watershed case study, the PSAH program case study and the Commons Levy case study are based on a regulatory framework defined at the municipal or national level. In fact, the main buyer of the ES is the municipality that catches the positive externalities generated by the sustainable management of natural resources through an additional tax that falls on citizens as final beneficiaries of the ES provided through the agreement between the municipality and the landowners. Instead, the Victoria BID and Adopt a green spot case studies are voluntary and are based on an agreement that various stakeholders (citizens, local businesses, universities, associations, etc.) decide to sign with the municipality to contribute to the implementation and management of NBS. The case Adopt a green spot case is particularly interesting as the municipality has defined two types of agreements with different characteristics: sponsorship and collaborations.

The first type of contract - sponsorship - implies the direct payment to the municipality of the amount necessary for the creation and management of the NBS. The second type of contract - collaboration - foresees that the contractor takes care of the implementation and management of the NBS following the standards defined by the municipality. The flexibility of the agreements defined allows for the involvement of different types of stakeholders. The Victoria BID case study is also based on a voluntary agreement that is defined by local business for the implementation of different measures aimed to improve the area attractiveness. Through the BID several NBS such as green roofs and green walls have been implemented. The BID contractors decide on a voluntary basis to pay an additional tax for the implementation of the NBS.

Two main categories of urban PES schemes have been identified: i) user financed PES, where users of generated ES pay implementers of NBS through voluntary agreements (Adopt a green spot; Victoria BID); ii) compliance PES, where users of generated ES pay a public authority or a delegated implementer of the NBS through mandatory taxes or charges (Catskill watershed, PSHA, Common levy). The common factor among the case studies analyzed is the role of promoter and guarantor that is carried out by the municipality or by a public entity, even if the PES schemes own to two different categories. In all cases, the municipality/public entity collects the funds paid by the users of the ES and distributes them to the provider of the ES. In addition, the municipality/public entity deals with defining the standard of service (e.g., “Adopt a green spot” and Victoria BID) or the rules for the sustainable management of ecosystem services (e.g., Catskill watershed and PSAH).

These characteristics seem peculiar of the urban PES analyzed. In fact, in literature there are several PES case studies in which a public authority is not included in the scheme. These are self-organized private deals in which beneficiaries of ES undergo contracts directly with service providers. The PES is designed through the definition of an ad hoc voluntary agreement between the two parties (buyer and seller), including the characteristics of the contract and the standards of service that the contractors must comply with. In the case of urban-scale PES, the role of the public body (or of a company partially controlled by the municipality that manages the execution of the scheme) plays a fundamental role. In fact, the presence of a public body can ensure greater trust in the execution of the PES, so providing greater guarantees to stakeholders who decide to or are obliged to join the initiative.

Although PES are instruments that have proven to be suitable for the implementation of NBS and for the engagement of different stakeholders in the sustainable management of ecosystems, the adoption of these instruments still presents some challenges. In the case studies analyzed it emerges that the PES are structured for the payment of a single ecosystem service, while economic, social, and environmental values of the other ES generated are not captured by the PES. In fact, not all ES produced by NBS are accounted in the PES schemes, but only one or a few services are traded whilst the values generated by other services are not captured. The correct enhancement and protection of the ES generated by NBS requires to identify and adopt systems for monitoring and measuring the impacts generated considering all the benefits and trade-offs (Salzman et al., 2018). The assessment of NBS in cities should take into account the plethora of impacts generated with attention also to the secondary impacts generated by NBS. For example, the implementation of a green roof can deliver several regulation services, such as climate regulation, air quality improvement and run-off mitigation. At the same time, green roofs can also improve the energy efficiency of a building or increase its attractiveness. Another challenge in the implementation of PES scheme in urban areas can involve social inequalities. At the urban level it must be considered that there will be spatial variation in the provision of the ES (Baró et al., 2016). According to some authors (Barnaud and Antona, 2014), PES can improve the provision of services only in certain areas of the city. For example, related initiatives such as land use planning for climate change adaptation have been found to exacerbate socio-spatial inequalities (Wen et al., 2013; Kabish et al., 2015; Anguelovski et al., 2016). Such variation raises challenges for designing PES schemes and impacts the feasibility of PES in urban areas (Richardson and Thompson, 2018). Hence it is necessary to ensure that participation in PES is accessible to different stakeholders and benefits are well distributed in different parts of the city. Finally, it must be considered that ES demand can vary based on several drivers such as climatic conditions (Mora et al., 2017), cultural background (Akbari et al., 2001), and socio-economic characteristics of urban residents (Casado-Arzuaga et al., 2013; Zezza and Tasciotti, 2010). Applying PES in an urban context is far more challenging than in rural areas, where there is a less complex set of stakeholders and where computing benefits and costs is more straightforward (Davies et al., 2018). Indeed, the complexity of urban environments and the interactions between many ES requires a holistic perspective to ensure that the values generated by NBS implementation can be adequately accounted and allocated.

5 The urban PES model for diffused green areas maintenance in Milan

Abstract

In 2005 Milan Municipality launched the “Adopt a green spot” model initiative, to restore and maintain scattered and marginal green areas, following a Payment for Ecosystem Services (PES) scheme. The PES scheme was designed in the form of two standardized typologies of voluntary agreements – sponsorship and collaboration - allowing flexibility in the commitment of involved private stakeholders, including condominiums, NGOs, and the business. The model has been replicated over the years and 502 agreements, for a total surface of 265.398 m^2, have been signed up to now. The analysis focuses on the design components of the PES scheme which determined its capacity to be replicated in different contexts involving a variety of stakeholders. The main elements enabling the success of the PES scheme are i) the flexibility of the voluntary agreements designed to meet the needs of various stakeholders; ii) the variety of green areas included in the initiative: in particular the prevalence of small size areas allow the participation of stakeholders with low economic capacity; iii) the public recognition through the advertising plate which makes it possible to attract firms iv) the low transaction costs borne by the stakeholders who decide to join the initiative. The “Adopt a green spot” PES scheme gives value to a specific ecosystem service (ES), i.e., the aesthetic appreciation generated by the improvement of the area. The financial resources committed, even if representing a small portion of the total social benefit generated, are sufficient to ensure an adequate requalification and maintenance of small green areas, often neglected because of scarcity of public financing.

The standardization of the contracts between the Municipality and private stakeholders, the flexibility in the choice of requalification and maintenance formula, and the accessibility to all kinds of interested stakeholders ensure low transaction costs, so avoiding a relevant barrier characterizing most PES schemes.

The replication capacity of this PES scheme makes it a model initiative. Given its characteristics and flexibility, it has been used for the definition of more than 500 agreements with different stakeholders, and for these reasons the policy design approach can be suitable for the replication in other urban contests.

5.1 Market-based instruments for NBS implementation

Despite evidence of benefits generated by ES and NBS, highlighted in Chapter 1 and Chapter 2, cities are still facing difficulties in introducing measures – such as nature-based solutions (NBS) – to protect and reinforce ES. The enhancement of ES depends also on the capacity of local governments to introduce instruments to protect and facilitate the implementation and management of green areas in cities (Naeem et al., 2015). Between the three categories of policy instruments described in Chapter 1 (regulative instruments, market-based instrument, and information/knowledge-based instruments), market-based instruments are particularly interesting for the implementation of NBS at the urban scale. Market-based instruments influence actors' behavior by changing their economic incentive structure. Environmental externalities, such as damages caused by GHG emissions, are usually not reflected in consumption or investment decisions but are nonetheless imposed on third parties. Market-based instruments work by reflecting the environmental impact of a certain action by attaching a cost to it, to provide an incentive to the polluter to reduce his impact. Different instruments are included in this category, such as incentives, taxes, etc. An innovative instrument that falls under this category is Payments for Ecosystem Services (PES). In most cases, PES has been designed for the management of ES outside of cities' boundaries (Smith et al., 2013) but they can also play a relevant role at the urban level in enabling the involvement of stakeholders for implementing and managing different infrastructures such as NBS even if their adoption is still not widespread at the city level (Cerra, 2017; Richards and Thompson, 2018). Nonetheless, instances of successful business-funded PES in urban areas do exist, as demonstrated by different schemes.

The case study "Adopt a green spot" has been implemented in the city of Milan since 2005 and replicated over 500 times up to now, providing relevant and diffused social impact, to investigate the key design elements of an urban for the protection, implementation, and management of green spaces. In fact, the initiative can be interpreted as a PES, where the Municipality is the owner of the natural resource providing ES, while citizens and other stakeholders are the beneficiaries of the ecosystem services provided by the green areas. The impacts generated by the initiative (distribution of green areas under the scheme, stakeholders involved, investments made,) are analyzed. The analysis highlights the elements for a successful policy design of an urban PES able to involve a wide range of stakeholders, and to be replicated in a variety of contexts., The analysis is structured as follows: i) analysis of PES scheme, ii) methodology, iii) description of the initiative iv) assessment of the results; and v) discussion.

5.2 Characteristics of urban PES

The concept of PES is based on the idea that the beneficiary of an ES should reward the owner of the natural resource generating the service to ensure its maintenance or to improve its conditions. Wunder (2015) defines a PES as "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services". These characteristics aim to incorporate the economic value of ES into the decision-making of producers and consumers. PES schemes allow service buyers to pay for the safeguard of a natural resource and the services it provides on which they are reliant, hence preventing the risk it becomes scarce, and to compensate for the negative externalities caused by production or consumption activities to the society (UNEP, 2009). In this way, it is possible to change those behaviors which harm ecosystems (Rojas and Aylward, 2003). Different categorization of PES are possible. In particular, Salzman et al., (2018), identified three typologies of PES based on their financing model: User-financed PES, Government-financed PES and Compliance PES (see Table 13).

User-financed PES	Users of ES compensate landowners to maintain or enhance the delivery of ES of which they are direct beneficiaries
Government-financed PES	Public entities compensate landowners to maintain or enhance ES delivery of which users are beneficiaries.
Compliance PES	Parties facing regulatory obligations compensate other parties for activities to maintain or enhance ES in exchange for a standardized credit or offset that satisfies their mitigation requirements

Table 13: PES schemes categorization (authors elaboration on Salzman et al., 2018)

The PES typologies described differ based on i) the buyer of the ES, ii) the nature of the agreement that can be voluntary or non-voluntary. In the User-financed PES direct users of ES compensate landowners for activities that maintain or enhance ES delivery, and it is regulated through a voluntary agreement signed between the contracting parties, while in a Government-financed PES the government compensates the owner of the natural resource providing the ES as a public good. In Compliance ES users face regulatory obligations to compensate ES providers for activities that maintain or enhance ES of which they are not direct beneficiaries in exchange for standardized credits or offsets that satisfy their mitigation requirements under the scheme they have to comply with (example of such schemes are: water quality trading, GHG emission trading, etc.). An important feature of PES lies in their flexibility. PES schemes can be structured based on the ES to be protected, on territorial scale and context, as well as on payment mechanisms and sources. Nonetheless, applying PES in an urban context is far more challenging than in rural areas, where there is a less complex set of stakeholders and where computing benefits and costs is more straightforward (Davies et al., 2018). Indeed, the complexity of urban environments and the interactions between many ES require a holistic perspective to ensure that maximum benefits can accrue to beneficiaries (Richards and Thompson, 2018). As stakeholders have different needs (Baró et al., 2016), such variety can raise challenges for designing PES schemes and impacts the feasibility of PES in urban areas (Richardson and Thompson, 2018). Moreover, ES demand can vary based on climatic conditions (Mora et al., 2017), cultural background (Akbari et al., 2001), and economic characteristics of citizens (Casado-Arzuaga et al., 2013; Zezza and Tasciotti, 2010). A further barrier to the implementation of PES at the urban level is the lack of innovation capacity, which keeps local authorities from trying something new enabling the active participation of all stakeholders in the conservation of urban greening. The fear of failure inhibits policy innovation, leading governments to suppress new ideas and to avoid risky concepts (Kuyatt, 2011). It is often the case where the possible ES provider is not even aware of the concept of PES (Eves et al., 2014). In this regard, public authorities can act as facilitators or regulators, providing a framework to stakeholders potentially involved in a PES scheme. A final barrier to the successful implementation of a PES scheme is free-riding behavior. The risk of free-riding is amplified in the urban setting. The high density of actors implies that service providers will deal with several potential beneficiaries, so some stakeholders might take advantage of the PES scheme impacts without taking part in it (Richards and Thompson, 2019). The involvement of resource appropriators in the management of collective goods is one of the fundamental elements identified by Ostrom (Ostrom, 1990) to successfully preserve such goods, and avoid the free-riding problem which is at the base of the "tragedy of the commons" (Hardin, 1968). According to Hardin, this situation occurs in a shared-resource system when individuals act independently by trying to maximize their gains, thus leading to the shared resource being depleted through their collective action. In this case, the role of the local (or national) government is fundamental to engage different stakeholders in the preservation and protection of a common good. This can be realized through the introduction of standards, or mandatory obligations, or awareness-raising campaigns. By taking into consideration the barriers listed above, the application of a PES scheme at the urban level can be quite challenging. Despite this, several cases of implementation of PES at urban scale can be found even if they have been scarcely analyzed[7].

Even if PES schemes are recognized as a suitable instrument for the enhancement and protection of ES at different scales, the widespread adoption of PES needs to overcome several barriers, so requiring structuring schemes to ensure their effectiveness. Based on the literature the main obstacles lay in the

[7] A literature review performed though Scoups, by using the keywords Urban+PES, has provided only four case studies

design and payment structure (Engel et al., 2008; Adhikari and Boag, 2012); the modes of implementation (Engel and Palmer, 2008; Zhang and Pagiola, 2011); the trade-offs management (e.g., social equity) (Pascual et al., 2010, Narloch et al., 2011); the monitoring approach (Wünscher et al., 2008); and compliance (Wendland et al., 2010). All in all, the main critique associated to PES approach is "the assumption that ES remuneration will ensure their provision" (Fairhead et al. 2012). The focus on monetary exchange values can hide the existing plurality of values generated by ES (Vatn 2010). Therefore, some scholars plead for a plurality of values in the context of nature conservation (Kallis et al. 2013, Muniz and Cruz 2015). If value plurality is not considered, a "potential crowding-out of intrinsic motivations is often mentioned as a barrier for successful nature conservation and ecosystem services enhancement" (Corbera 2012, Hahn et al. 2015, Scales 2015). However, it is controversial in literature whether PES contribute to an increase of commodification processes in conservation policies (Gómez-Baggethun et al. 2011, Wunder 2013). Furthermore, Wunder (2013) argues that PES schemes seldom use economic valuation, nor do they depend on markets. Instead, PES schemes enable participation and equitable conservation outcomes through their negotiated compensation logic (Schröter et al., 2014).

To overcome these critical issues related to PES schemes, their implementation requires three main conditions: economic, cultural, and institutional (Ferraro and Kiss, 2002; Wunder, 2005; Engel et al., 2008; Fripp, 2014). The economic condition implies that the users' maximum willingness to pay corresponds to or is higher than the providers' minimum willingness to accept the compensation. If this did not occur, then the service provided would be assessed less than the estimated cost provision landowners are facing for deviating from their land-use plan. The cultural condition implies that service users are willing to pay for the ES, and the providers are willing to change their management habits of the natural resource that produces a specific ES (Richards and Thompson, 2018). The institutional condition implies that a third party (e.g.: public authorities, external intermediaries, etc.) can create trust between actors to ensure correct PES scheme execution (Salzman et al., 2018). Consequently, a PES scheme requires complex interactions over time; if all parties were to act independently in perfectly competitive markets, transaction costs would be enormous given the number of different actors to be involved. Transaction costs include time taken to agree on the nature, extent and timing of the payments or in-kind transfers, drawing up contracts, and monitoring the outcomes of the agreement for all parties (Jindal and Kerr, 2007). Some studies find that high transaction costs can represent a substantial obstacle for the participation in PES schemes (Behera & Engel, 2004; Engel et al., 2008; Locatelli et al., 2008; Wunder, 2008; Smith, 2013). Finally, PES cannot function without tenure clarity and security. If such well-defined stewardship does not pre-exist, then local land users will lack the crucial right to exclude third-party access, making them unreliable service providers with insufficient control over service delivery (Wunder, 2015).

The design and implementation of PES in urban contexts requires to specifically apply the three conditions described above. Differences in economic conditions, and so in availability to pay condition the possibility to access to a PES scheme. This can lead to a concentration in the participation to PES schemes, and consequently the connected generation of benefits, in the wealthier urban areas. Moreover, cultural conditions can influence the perception of nature. The diversity of stakeholders that interact at urban scale, and the variety of their backgrounds make the definition of a PES scheme able to fit with the different perceptions and expectations more difficult. In this context the role of local governments is crucial to identify flexible schemes that allow engaging different stakeholders considering their social, economic, and cultural diversity. Municipalities can act as regulators and controllers of PES schemes to improve their management and to compensate for possible differences in the localization of benefits.

Nevertheless, urban PES can take advantage of factors such as the proximity of stakeholders and clearly defined policy and regulatory frameworks under the influence of the municipal local authority. This can lead to a more stable framework, easier monitoring, verification, and enforcement of agreements, and higher potential of standardization and replicability of schemes.

5.3 “Adopt a green spot” initiative – description and peculiarities

The city of Milan has a population of almost 1.4 million inhabitants, a surface of 181,8 $km^{2,}$ and a density of over 7.5 thousand inhabitants/km^2. The city is divided into 9 districts: numbering starts from the historic city center, which is enclosed by the inner ring road, and then continues clockwise starting from the north-eastern sector of the city (Figure 9) District 1, the historic district, is the main commercial and tourism hub.

Other major commercial and touristic areas are found within districts 3 (Buenos Aires Avenue), 4 (Porta Romana), 6 (Navigli and Tortona design hub) and 8 (CityLife). The main business districts are number 8 and 9. Residential areas can be found in all city districts’ excluding district 1. A study by Boatti A. et al, (2017) investigated the distribution of property value across the municipality of Milan. Although the outskirts have undergone regeneration projects, these are still poorer compared to the areas next to the city center and the city center itself. Hence, there is still a strong differentiation between the residential areas within the outer ring road and those outside of it. When looking at the population per district, district 1 – the city center – has the lowest figure with 97.403 inhabitants in 2017. In fact, In other districts than the city center, population ranges from 125.000 to 186.000 inhabitants.

The total green area surface of the city of Milan is 17.813.011,5 m^2 [8], which is equivalent to 12.9 m^2 of green space per inhabitant (the value is lower than the national urban average which is 18 m^2/inh.). Green areas are differently distributed within the city, Map 1 shows a greater concentration in the peripheral areas where the larger city parks are located. Though historic parks are located in district 1, this is the one with the least availability of green areas per inhabitant (7,9 m^2/inh.) preceded only by district 2 (6,7 m^2/inh.). Only district 7 shows urban green space above national average, with 20 m^2/inh., while all other districts present between 10 and 16 m^2/inh.

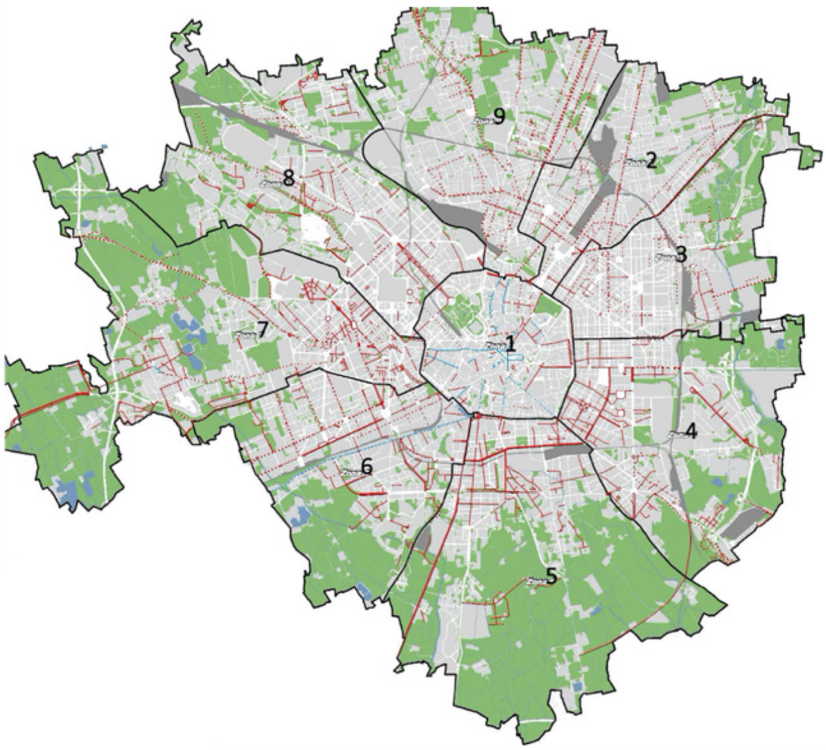

Figure 9: Milan Municipality districts and green area distribution

In the last years, the Municipality implemented several measures for the enhancement and expansion of green areas. The paper takes into consideration the impacts generated by the "Adopt a green spot initiative", launched by the municipality in 2005. The initiative aims to engage various stakeholders in the management of green areas: citizens, condominiums, NGOs, business, and universities can participate providing for the improvement and maintenance of green areas through the signature of

[8] Data do not include green areas that are not usable by citizens, such as agricultural areas.

standardized voluntary agreements designed by the Municipality. The initiative foresees the possibility of the adoption of different typologies of green areas, such as: portions of urban parks and gardens, recreational areas, flowerbeds, roundabouts, tree lines, and trees. A list of available green areas is reported in the Milan Municipality website.

The “Adopt a green spot” initiative includes two types of agreement: sponsorships and collaborations. The private partner that aims to join the initiative through the Sponsorship agreement must i) identify the area that is to be "adopted", ii) define a project proposal, ii) draw up a technical relation (including the characteristics of the plants and their maintenance) and iii) define a financial plan for the green area realization and maintenance. If all of them are approved by the Municipality the private partner can access the initiative. By signing the agreement, the private partner (the contractor) will provide the Municipality an economic contribution to project implementation and maintenance. Within the agreement, responsibilities, duration of the agreement, obligations of the sponsor, obligations of the Municipality, penalties, and costs are defined. Finally, the Municipality gives public recognition to the private actor that signs the sponsorship agreement through an advertisement plate placed in the green area. Sponsorship agreements last for 3 years. Sponsorship agreements provide for a second way of joining the initiative. The private partner can decide to access the initiative through a donation for the maintenance of a green area, leaving the task of defining the project to the Municipality. In this case, the private partner will not have to submit the project proposal, the technical report, and the financial one. This type of sponsorship agreement also provides for public recognition to the private actor through an advertisement plate placed in the green area.

The second typology of the agreement is Collaboration. The private partner that aims to join the initiative must i) identify the area that is to be "adopted", ii) define a project proposal, and ii) draw up a technical relation. The eligibility of the project depends on several criteria set by the Municipality. If the project is accepted, the private partner can access the initiative. Once the contract with the Municipality has been signed, the private partner must implement the project within 60 days. Through Collaboration agreement, the direct implementation of the project proposed, and its maintenance is taken on by the private partner. The agreement also defines the area maintenance standards, the environmental requirements to be met, the penalties, and the monitoring process. Once the project takes off, the Municipality monitors the project implementation and the green area maintenance through a dedicated municipal office to ensure the private partner complies with the standards defined by the agreement. Collaboration agreements last for 5 years. Table 14 summarizes the main characteristics of the two agreements defined by Milan Municipality.

	SPONSORSHIP AGREEMENT	COLLABORATION AGREEMENT
Project design	Private partner	Private partner
Financial plan	Yes	No
Project implementation	Private partner/Municipality	Private partner
Maintenance	Municipality	Private partner
Monitoring	Municipality	Municipality
Advertisement plate	Yes	No
Duration	3 years	5 years

Table 14: Sponsorship and collaboration agreements characteristics

Three main characteristics distinguish the two types of agreement. The first concerns financing of the project. In the case of sponsorship, the private partner must submit a financial plan describing project implementation and maintenance costs. Instead, which is not required in the collaboration agreement. The second difference lies in the implementation and maintenance phases. As regards the sponsorship agreement, the private partner can decide whether to directly implement the project or whether to delegate the responsibility to the Municipality; however, as regards maintenance, responsibility is always borne by the Municipality while expenses are entirely covered by the private partner. Instead, in the collaboration case, the private partner takes direct care of implementation and maintenance of the project. Finally, the last feature that distinguishes the two agreements concerns public recognition. In the case of sponsorship, an advertising plate is put in the green area for the entire duration of the contract, which is not envisioned in the collaboration agreement.

The initiative launched by the Municipality of Milan can be interpreted as a PES, where the Municipality is the owner of the natural resource providing ES, while citizens and other stakeholders are the beneficiaries of services provided by green areas (see Figure 10 a and b).

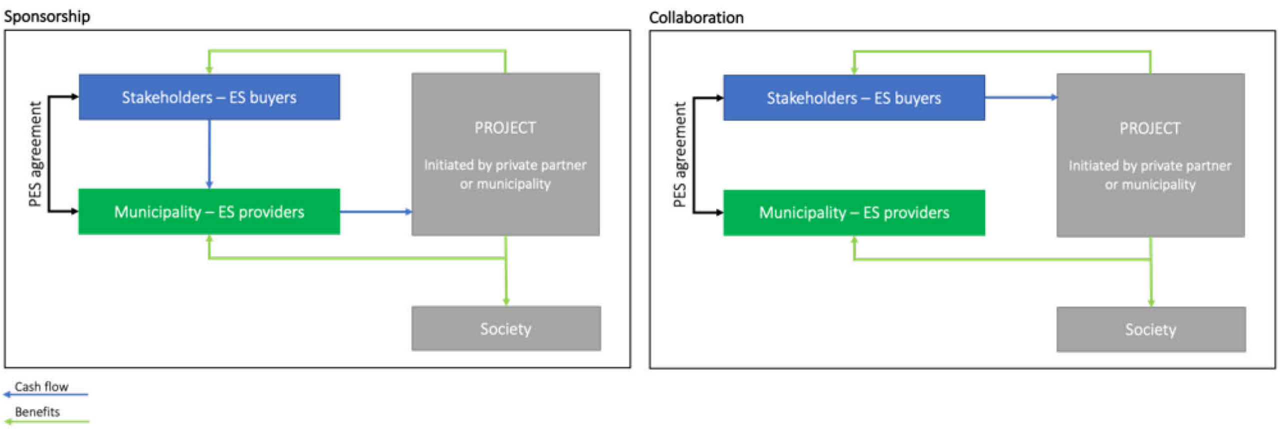

Figure 10: A - Milan "Adopt a green spot" PES scheme – sponsorship agreement; B - Milan "Adopt a green spot" PES scheme - collaboration agreement

The definition of two types of standard agreements by the Municipality facilitates the engagement of different categories of stakeholders in maintenance of t natural resources and ES provided by them. To better analyze the structure of the PES scheme, four main elements are here highlighted: i) ES buyers; ii) ES sellers; iii) payment for the provision of ES and iv) benefits generated by ES.

Benefits generated by enhancement of ES through maintenance of urban green areas do not only provide benefits to stakeholders who decide to join the initiative but also to the Municipal administration (e.g., decrease in maintenance costs of green areas) and more generally to all citizens (e.g., improvement of aesthetics of areas).

Among the various ES generated by green areas, the PES scheme implemented in Milan considers only aesthetic appreciation. In fact, stakeholders decide to sign an agreement to improve the quality of a green area within their neighborhood. Instead, other ES provided by a green area – such as climate regulation, CO_2 capture and storage, pollutant removal, etc. - are not considered. Aesthetic appreciation is part of "cultural ES category (MA, 2005)". Cultural ES provide non-material benefits people obtain from nature (TEEB, 2010) such as aesthetic appreciation, cultural identity, sense of place, education, physical and mental health, social integration (Gómez-Baggethun et al., 2013, Schmidt et al., 2016) all of which account for a large proportion of ES in an urban context (Wu, 2013). This category of ES can play an important role in the improvement of urban spaces and human well-being. Despite this, their importance is often overlooked in urban planning (Ahmed et al. 2019). Incorporating cultural ES into urban planning and policy making could help to increase awareness of nature as a critical component of human health and well-being. Research identified a connection between cultural ES and public engagement (Colding and Barthel 2013, Andersson et al. 2014, Gould et al. 2014, Chakraborty et al. 2020). Some studies highlight that individuals and communities prefer to support initiatives when they improve cultural ES (Dendoncker et al. 2013, Andersson et al. 2015). For example, Erickson et al. (2002) demonstrated aesthetic appreciation was the main driver for retaining woodlots in Michigan (Erickson et al., 2002) and research on voluntary environmental engagement highlights main motivations are learning about nature (Andersson et al., 2015). Furthermore, the engagement of people in cultural ES stewardship could increase the awareness of several benefits generated by other ES since cultural ES are often generated interdependently with other ES (Milcu et al., 2013, Jennings et al., 2016).

5.4 Approach and drivers considered for the Milanese PES scheme analysis

The paper analysis the design components of the Milan "Adopt a green spot" PES scheme as determinants of its capacity to be replicated in different contexts involving a variety of stakeholders.

Data used to perform the initiative assessment include information from 2005 (year of launch) to 2019 and have been provided by the Green, agricultural, and urban furniture department of Milan Municipality. As data used for this study have been extracted from the Municipality database in February 2019, data for year 2019 are partial.

A set of suitable indicators has been identified to assess the overall impacts generated by the adoption of the PES scheme: i) number of signed contracts (in total and per typology), ii) typologies of stakeholders engaged in the initiative, iii) typology of agreement selected by different stakeholders' categories, iv) total investments, and v) investment per square meter. These indicators have been selected based on the peculiarities of the scheme (see section 2) to assess: capacity to involve buyers and sellers of ES (number of contracts signed), capacity to attract investments for the enhancement and maintenance of ES (total investments generated and investments made per m^2), and capacity to involve different stakeholders (typologies of stakeholders engaged in the initiative and typology of agreement selected by different stakeholders).

These indicators have been analyzed also through a spatial analysis to investigate how their values vary with the considered areas of the city. More in detail the research question investigated using the spatial analysis is whether the PES scheme has different impacts based on the localization of the green areas. In fact, the spatial analysis approach allows creating a detailed picture of the initiative impacts by adding the geospatial variable to the assessment. Data analysis through GIS can provide a powerful new perspective in addressing research at the urban level and in understanding policy effects (Worral and Bond, 1997; Henderson, 2008). The GIS tool provides a significant opportunity to improve the effectiveness of policy and the efficiency of programs implemented in cities (Worral and Bond, 1997). In fact, spatial analysis can be used to assess the degree of correlation between observed values in geographic space (Rey, 2001) and it reveals the spatial patterns among observations, which can be investigated both globally and locally (Liu et al., 2021). Indeed, spatial analysis allows grasping the mechanisms underlying the phenomenon analyzed. In the paper, the indicators used for impact assessment have been combined with green areas' localization. More in detail, spatial analysis allows to correlate the six above mentioned categories of indicators with the localization of the green areas through-out the city. The spatial analysis has been used to assess the variability of the indicators per each administrative district of the city and the variability of the indicators based on the distance from the city center (in this case, the analysis has been performed by considering 500-meter buffer starting from the city center).

Through the applied methodology, it is possible to assess: i) number and typologies of involved stakeholders; ii) total green areas managed through the initiative; iii) total investments made by different typologies of stakeholders, iv) type of agreement selected by different typologies of stakeholders; v) distribution of contracts in different areas of the city, and iv) distribution of investments in different areas of the city.

5.5 Emerging results of the Milanese payment for ecosystem services scheme

Figure 11 shows the number of new contracts signed each year since the launch of the initiative from 2005 to 2019 (the data used for this study has been extracted from the Municipality database in February 2019 therefore the data for 2019 are partial).

The different stakeholders who joined the initiative are grouped into companies, condominiums, NGOs, private citizens, and universities/schools. Among the 502 agreements, companies took part to 37% of the agreements, condominiums to 40,6%, NGOs, to 10,1%, private citizens to 11,2%, and universities/schools to1%. More in detail, as of 2019, 502 agreements were signed between the municipality and private partners; they covered 265.398,47 m^2 of green areas and the total investment amounted to 2.583.841,01 €.

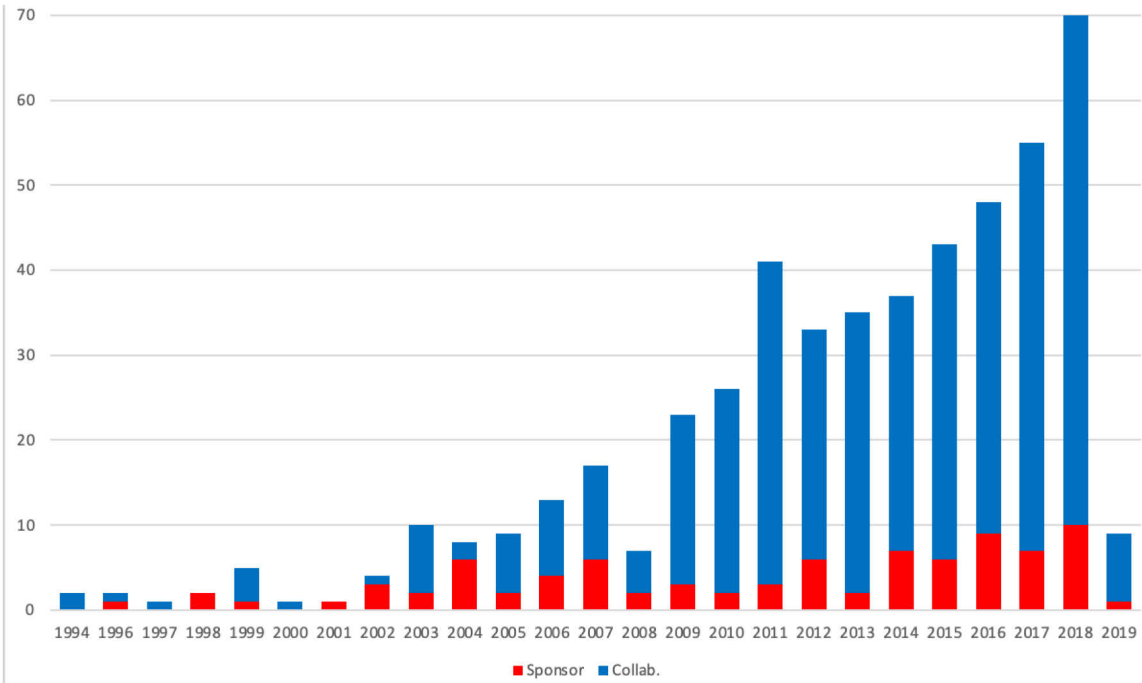

Figure 11: New agreements signed each year from 2005 to 2019

The green areas under the initiative include flowerbeds, urban parks and gardens, recreational areas, roundabouts, and single trees. Areas range between 50 m^2 and 30.000 m^2. The graph below (Figure 12) represents the green areas' distribution between 6 ranges of dimensions.

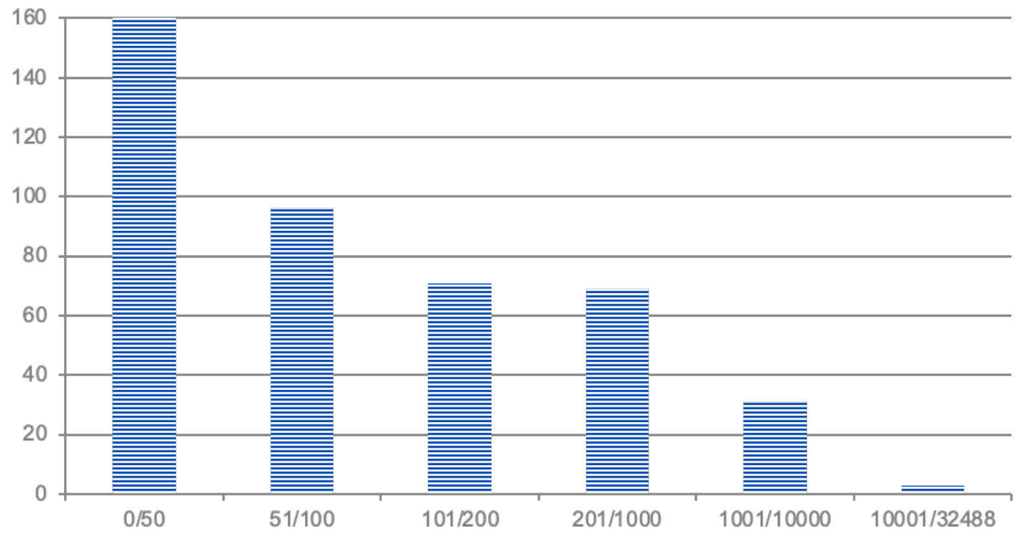

Figure 12: Distribution of the green areas under the initiative based on ranges of dimensions (m^2)

Among the 502 agreements signed between the municipality and private partners, 415 are collaborations and 87 sponsorships, respectively covering 196.537,64 m^2 and 68.860,83 m^2 of green areas. Total investments amount to 837.473,63 € for collaborations and to 1.746.367,38 f€ or sponsorships. Investments per square meter amount to 4.26 €/m^2/year for collaborations and 25,36 €/m^2/year for sponsorships. Results are described in detail in the following paragraphs: 5.5.1 depicts the results of the analysis per district whereas 5.5.2 those per 500-meter buffer.

5.5.1 Analysis per city districts

The section describes the results obtained from the GIS analysis that was carried out to investigate the distribution of agreements, of the stakeholders, and of the investments based on the districts. So, it is divided into three parts to deal with i) the distribution of agreement types, ii) the distribution of the investments (in total and per square meter), and iii) the distribution of stakeholders involved in the initiative. All in all, results show that the highest concentration of agreements is located in district 1 and in the areas of the other districts right next to it, with sponsorship being more diffused in the city center whereas collaborations are more diffused in districts 7 and 8. The major amount of investments come from sponsorship and are located in the central area of the city. Finally, companies prefer investing in the city center, whereas private citizens and condominiums in districts 7 and 8. The analysis highlights those collaborations, which are mainly found in residential areas, are preferred by private citizens and condominiums, whereas companies invest in the city center through sponsorship agreements.

5.5.1.1 Spatial distribution analysis of number of agreements per city district

The analysis on the spatial distribution of each type of agreement within the municipality of Milan is represented in Figure 13 (the red spots represent the sponsorship agreements and the blue ones the collaboration agreements). Furthermore, data on number of agreements by agreement type per each district are reported in the Table 15.

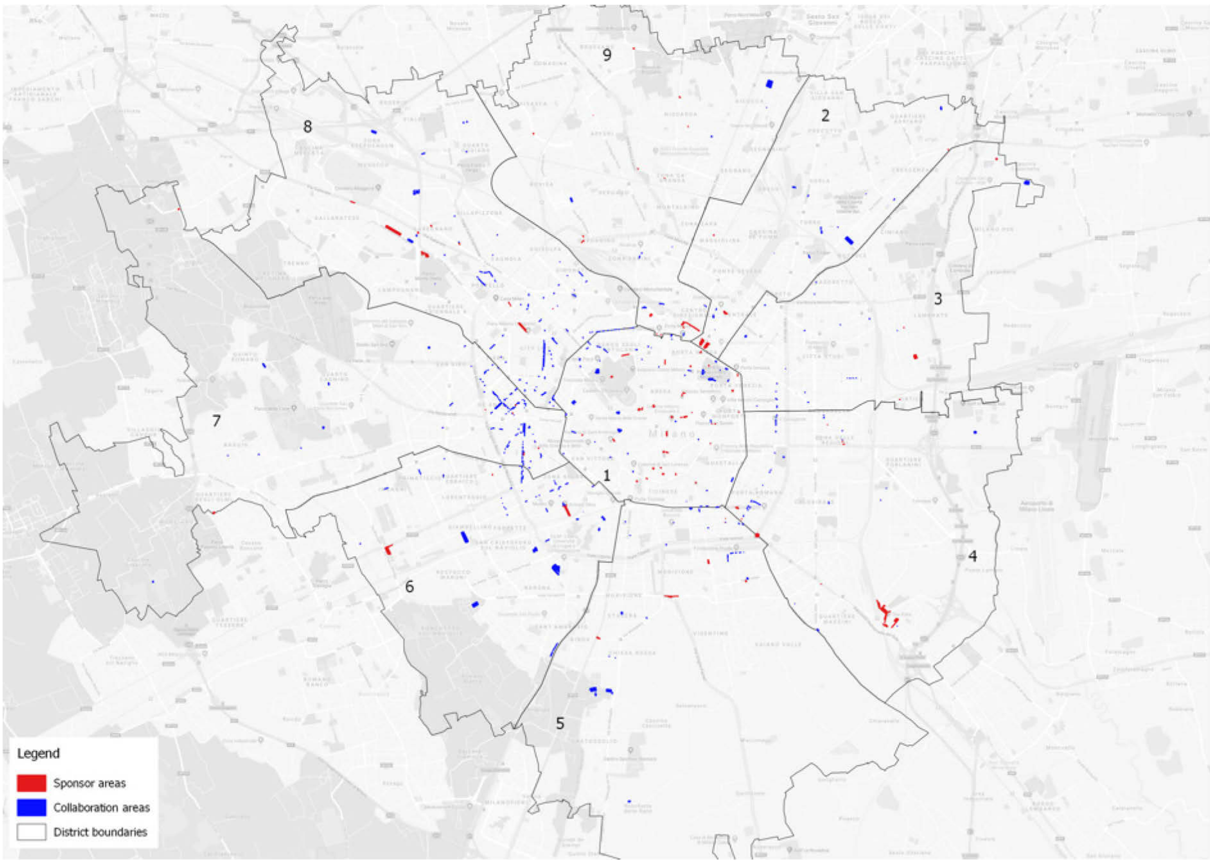

Figure 13: Distribution of agreements per district based on their type

DISTRICT	1	2	3	4	5	6	7	8	9	TOT
Sponsor	29	5	4	11	7	2	7	9	13	87
Collaboration	66	17	22	35	19	48	115	80	13	415
TOTAL	95	22	26	46	26	50	122	89	26	502

Table 15: Distribution of Sponsorship and Collaboration contracts per district

Out of the 502 agreements, the highest concentration of agreements is located in district 7 (122 agreements). Except for districts 1 and 8, the other districts have at most 50 agreements. Sponsorships are mainly concentrated in district 1 (29 agreements), whereas most collaborations are found in district

7 (115 agreements). The map shows that agreements are more numerous in the city center and in the areas of the other districts right next to district 1, whereas the further from the city center, the more scattered agreements are. The city center boasts the highest concentration of sponsorship agreements among all districts, but also a significant amount of collaboration ones is present, although collaborations are more abundant in districts 7 and 8, which are characterized by a high concentration of residential areas.

5.5.1.2 Spatial distribution analysis of investment costs per city district

The revenues raised through the collaboration and sponsorship agreements have been computed both per square meter and in total for the 9 districts. Results show that District 1 boasts the highest amount of investments (914.802,33 €), as well as the largest sponsorship investments (843.188,09 €) – half of the total sponsorship investments -, whereas the largest collaboration investments are found in district 6. Investment per square meter allows for a better comparison of the districts because it can be used as an indicator for the value attributed to green areas in a specific district. Sponsorship investment per square meter in the city center is 67,94 €/m^2, almost three times as much as the city average, a much higher figure compared to any other district. This is due to the high concentration of sponsorships in the city center. Indeed, overall, sponsorships attract more investments than collaborations, with an average of 25,36 €/m^2 compared to 4,26 €/m^2 for collaborations. Sponsorship investment per square meter is highest in district 1 with 67,94 €/m^2, whereas collaboration investment per square meter is highest in district 2 with 5,31 €/m^2). Results are summarized in Table 16. More in detail, the table shows the amount of revenues generated by green areas by type of agreement per district (€) and per square meter (€/m^2).

DISTRICT	1	2	3	4	5	6	7	8	9	TOT
Sponsor €	843.188,09	335.184,00	22.475,57	172.065,07	68.430,77	45.610,79	41.919,31	125.574,60	91.919,18	1.746.367,38
m2 Sponsor	12.411,53	10.098,68	1.757,80	12.395,73	3.759,18	7.058,04	2.891,66	13.300,10	5.188,11	68.860,83
Sponsor €/m2	67,94	33,19	12,79	13,88	18,20	6,46	14,50	9,44	17,72	25,36
Collab. €	71.614,24	61.470,32	20.135,73	73.450,77	80.883,74	278.664,70	71.946,16	84.648,93	94.659,04	837.473,63
m2 Collab.	17.946,90	11.580,62	5.997,67	15.139,36	16.215,49	60.802,87	16.859,86	20.874,23	31.120,65	196.537,64
Collab. €/m2	3,99	5,31	3,36	4,85	4,99	4,58	4,27	4,06	3,04	4,26
Total	914.802,33	396.654,32	42.611,30	245.515,84	149.314,51	324.275,49	113.865,47	210.223,53	186.578,22	2.583.841,01

Table 16: Amount of investment per district and per square meter by agreement type

5.5.1.3 Spatial distribution analysis of the stakeholders per city district

The stakeholders engaged in the initiative are distributed in different areas of the city in terms of signed agreements. Companies are the main signing party in district 1. Condominiums and private citizens instead reach their highest in district 7 with a total of 79 agreements for condominiums and 18 for private citizens. Agreements signed by NGOs are spread evenly throughout the city, with a maximum of 9 agreements in districts 1, 2, and 8. Instead, universities/schools signed only 5 agreements.

The city center and districts 7 and 8 are where most agreements are concentrated. Companies prevail in district 1 and are quite abundant in district 8 as well. However, condominiums are the main stakeholders in districts 7 and 8; in particular in district 7 they hold two-thirds of the total contracts. In general, companies prefer the city center, whereas condominiums and private citizens are more likely to invest in residential areas. Finally, the agreements signed by universities/schools are concentrated around university campuses. These results highlight that each stakeholder has different incentives to invest and preferences over which type of agreement to choose. The distribution of the stakeholders engaged in the initiative are summarized in Table 17 which shows the number of agreements per district.

DISTRICT	1	2	3	4	5	6	7	8	9	TOT
Company	45	7	13	19	14	15	21	32	20	186
Condominium	26	2	9	16	5	28	79	37	2	204
NGOs	9	9	1	4	7	5	4	9	3	51
Private citizens	13	4	3	7	-	2	18	9	-	56
University/School	2	-	-	-	-	-	-	2	1	5
TOTAL	**95**	**22**	**26**	**46**	**26**	**50**	**122**	**89**	**26**	**502**

Table 17: Number of agreements per district by stakeholder type

5.5.2 Analysis of distribution per buffer

The section reports the results obtained through the GIS analysis by 500-meter buffer. The section is divided into three parts to describe the results related to the assessment of i) the distribution of agreement types, ii) the distribution of the investments, and iii) the distribution of the stakeholders involved in the initiative. This further step allows to investigate whether the distance from the city center is a key driver for the concentration of agreements and the type of stakeholders involved.

All in all, results show that sponsorships are concentrated within a 3-km radius from the center of the city, whereas collaborations in the area between 1 and 4 km from the center; from 6 km onwards, the number of agreements starts to decrease sharply. Half of the total investments is located within the first five buffers (0-2500 meter). The first buffer displays the highest sponsorship investment, whereas the 4500-5000 meter buffer the highest collaboration investment.

When looking at investment per square meter, the figures for the buffers close to the city center are much higher compared to the rest in terms of sponsorships whereas collaborations are evenly spread out in all the city. Finally, the agreements signed by companies are very abundant in the buffers close to the city center, whereas citizens and condominiums prevail in the area from 2 to 4,5 km from the central point. Such results are consistent with those of the analysis per district: companies invest heavily in the city center, in the buffers 0-1500 meter, through sponsorships, whereas citizens and condominiums rely more on collaborations and prefer residential areas from 1 to 5 km from the center of the city.

5.5.2.1 Spatial distribution analysis of the agreements per buffer

Spatial distribution of each type of agreement based on the distance from the center of the city is represented in Figure 14 (the red spots represent sponsorship agreements and the blue ones' collaboration agreements). Furthermore, data on number of agreements are reported in the Table 18.

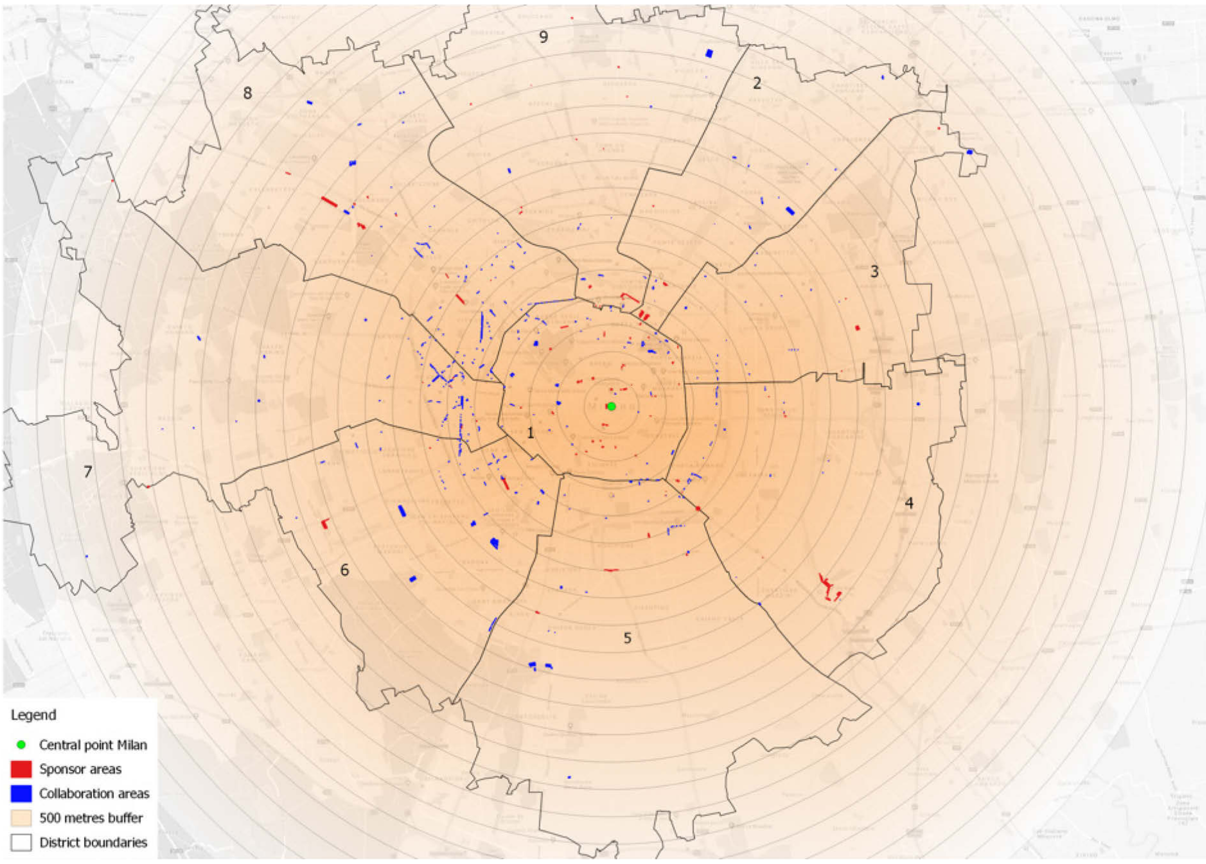

Figure 14: Distribution of agreements per 500-meter buffer based on their type

BUFFER meter	0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500
Sponsor	5	11	7	15	8	6	7	4	2	4	2
Collaboration	1	5	20	42	87	93	77	27	15	15	8
TOTAL	6	16	27	57	95	99	84	31	17	19	10

BUFFER meter	5500-6000	6000-6500	6500-7000	7000-7500	7500-8000	8000-8500	8500-9000	9000-9500	9500-10000	10000-10500	TOT
Sponsor	5	5	-	3	1	-	1	-	-	1	71
Collaboration	7	6	5	-	4	2	-	-	1	-	390
TOTAL	12	11	5	3	5	2	1	-	1	1	461

Table 18: Distribution of Sponsorship and Collaboration contracts per district

The highest concentration of agreements is found in the buffer 2500-3000 meter (99 out of 502). With the exception of buffers 1500-2000 meter, 2000-2500 meter and 3000-3500 meter, all the other buffers barely reach 30 agreements. Sponsorships are most numerous in buffer 1500-2000 meter (15 agreements), whereas most collaborations are found in buffer 2500-3000 meter (93 agreements). Overall, 52 out of 87 sponsorship agreements are located within a 3-km radius from the center, whereas more than 80% of the collaboration agreements are found in the area ranging from 1 to 4 km from the center (346 out of 415 agreements). The amount of both types of agreement sharply decreases in the outer buffers starting at 6 km from the center up to the city boundaries.

5.5.2.2 Spatial distribution analysis of investments per buffer

The spatial distribution of the investments shows that the largest amount of investments is concentrated within a 5,5-km radius from the center, for a total of 2.286.965,47 €[9]. With the exception of buffers 0-500 meter, 1500-2000 meter and 4500-5000 meter, all the other buffers are under 200.000 € of total investments. When taking into consideration also the surface area, sponsorship investments per square meter are much higher in the buffers adjacent to the city center (0-1500 meter), where they reach a maximum of 129,07 €/m^2 in the 0-500-meter buffer – more than 5 times the city average of 25,36 €/m^2 -, whereas collaboration investment per square meter is the highest in buffer 4000-4500 meter (5,03 €/m^2). More in detail, sponsorship investments per square meter are highest in the city center. Collaboration investments, instead, are evenly spread out from 500 meter to 6500 meter from the center, with significantly high values in buffers covering 4000-5000 meter. Finally, values decrease drastically beyond 7000 meters from the center. The total amount of investments and the investments per square meter of green areas by type of agreement per buffer are summarized in Table 19.

BUFFER meter	0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500
Sponsor €	376.417,58	162.497,94	170.909,97	245.505,00	336.394,83	33.059,19	72.187,40	24.961,20	22.765,20	15.326,37	134.403,33
m2 Sponsor	2.916,48	2.761,96	1.475,30	14.078,96	9.987,27	1.842,97	1.762,20	757,99	1.036,10	1.248,43	8.361,61
Sponsor €/m2	129,07	58,83	115,85	17,44	33,68	17,94	40,96	32,93	21,97	12,28	16,07
Collab. €	7,65	13.774,08	25.834,91	38.777,64	44.816,71	49.622,59	88.061,14	8.990,27	168.885,80	241.400,97	12.365,70
m2 Collab.	3,79	2.777,48	7.469,16	9.292,48	10.130,17	10.592,31	22.424,12	1.978,92	33.591,38	50.855,09	2.804,09
Collab. €/m2	2,02	4,96	3,46	4,17	4,42	4,68	3,93	4,54	5,03	4,75	4,41
Total	376.425,23	176.272,02	196.744,88	284.282,64	381.211,54	82.681,78	160.248,54	33.951,47	191.651,00	256.727,34	146.769,03

BUFFER meter	5500-6000	6000-6500	6500-7000	7000-7500	7500-8000	8000-8500	8500-9000	9000-9500	9500-10000	10000-10500	TOT
Sponsor €	66.106,79	46.200,90	0,00	7.248,00	9.882,00	0,00	10.387,08	0,00	0,00	12114,6	1.594.428,01
m2 Sponsor	11.405,20	7.359,71	0,00	949,34	630,32	0,00	1.937,00	0,00	0,00	350,00	68.860,83
Sponsor €/m2	5,80	6,28	0,00	7,63	15,68	0,00	5,36	0,00	0,00	34,61	23,15
Collab. €	17.803,36	18.087,61	65.782,73	0,00	15.534,86	15.304,64	0,00	0,00	12.423,00	0,00	692.537,44
m2 Collab.	4.694,12	4.196,95	21.417,45	0,00	5.301,10	4.909,04	0,00	0,00	4.100,00	0,00	151.918,99
Collab. €/m2	3,79	4,31	3,07	0,00	2,93	3,12	0,00	0,00	3,03	0,00	4,56
Total	83.910,15	64.288,51	65.782,73	7.248,00	25.416,86	15.304,64	10.387,08	0,00	12.423,00	12.114,60	2.286.965,45

Table 19: Amount of investment per 500-meter buffer and per square meter by agreement type

[9] The highest sponsorship investment of 376.417,48 € was made in the first buffer (0-500 meter), whereas the highest investment through a collaboration is located in buffer 4500-5000 meter (241.200,97 €).

5.5.2.3 Spatial distribution analysis of stakeholders per buffer

The analysis performed on the distribution of the stakeholders highlights how the different stakeholders are concentrated in areas of the city. More in detail, companies are the main stakeholder in the first four buffers (0-2000 meters). Right after the 1500-2000-meter buffer, although the agreement signed by companies are still numerous, condominiums take over and hold the most agreements in each buffer from 2500 meters to 4500 meters. The agreements signed by the NGOs are evenly spread across the city with a peak of 14 agreements in the 2000-2500-meter buffer. Over 70% of the agreements signed by private citizens are located within three buffers ranging from 2000 and 3500 meters. Overall, the agreements signed by companies are concentrated in the buffers including the city center. Although their presence does not fade away immediately, they are outnumbered by the agreements signed by the condominiums in the buffers from 2000 to 4500, where also most agreements held by private citizens is found. Starting from the 4000-4500-meter buffer, the number of contracts begins to decrease steadily until it gets to almost zero in the city outskirts. Table 20 shows the number of agreements per 500-meter buffer by stakeholder type.

BUFFER meter	0-500	500-1000	1000-1500	1500-2000	2000-2500	2500-3000	3000-3500	3500-4000	4000-4500	4500-5000	5000-5500
Company	6	10	16	33	28	23	21	11	4	8	3
Condominium	-	1	5	19	32	66	47	15	7	4	4
NGOs	-	4	2	4	14	2	3	1	3	5	3
Private citizens	-	1	3		21	8	12	4	3	2	-
University/School	-	-	1	1	-	-	1	-	-	-	-
TOTAL	6	16	27	57	95	99	84	31	17	19	10

BUFFER meter	5500-6000	6000-6500	6500-7000	7000-7500	7500-8000	8000-8500	8500-9000	9000-9500	9500-10000	10000-10500	TOT
Company	8	6	1	3	2	-	1	-	1	1	163
Condominium	1	-	1	-	-	2	-	-	-	-	200
NGOs	2	3	2	-	3	-	-	-	-	-	41
Private citizens	1	1	-	-	-	-	-	-	-	-	54
University/School	-	1	1	-	-	-	-	-	-	-	3
TOTAL	12	11	5	3	5	2	1	0	1	1	461

Table 20: Number of agreements per 500-meter buffer by stakeholder type

5.6 The limits and strengths of the Milanese model

Results show that the “Adopt a green spot” initiative has been effective in attracting economic resources aimed at the conservation and maintenance of green areas from different stakeholders in the Municipality of Milan. In total 502 agreements have been signed and 265.399 m^2 of green areas have been managed through the involvement of private stakeholders. Based on results described in previous sections it is possible to deduce that i) some types of contracts are preferred by different types of stakeholders engaged in the initiative; ii) different stakeholders prefer to invest in different areas of the city and iii) investments vary according to the areas. Characteristics of contracts preferred by different stakeholders can allow defining agreements that consider their specific needs and interests, thus making their involvement easier. Companies prefer to provide financial resources and then leave the implementation and management of green areas to the Municipality. On the contrary, citizens are more likely to directly take care of green areas. Results also show that different stakeholders prefer different areas of the city to invest in: companies prevail in the city center, while condominiums, along with private citizens, prevail in residential areas.

Regarding the distribution of agreements across the city, data show that sponsorships are concentrated in the city center and then scarcely scattered over the rest of the city, whereas collaborations are mainly located right outside the city center (see Map 2 and Map 3). Companies are more inclined to opt for sponsorship-type of agreement, whereas citizens prefer collaboration ones. The main results concerning investments made through the initiative show that the amount of investments vary based on the location of green areas. On one hand, the highest sponsorship investments per square meter are concentrated within the city center. Sponsorship investments are higher in the city center, where the sponsors benefit the most from visibility, start decreasing but are still substantial in residential areas, and finally decrease towards the outskirts of the city. Collaboration investments, instead, are smallest in the first buffer (0-500 meter) of the city center, where managing a green area would be prohibitive in terms of costs but grow significantly in residential areas. Hence, the higher the distance from the city center, the lower the investments in sponsorship agreements, whereas collaborations have a more homogeneous pattern throughout the city, with the exclusion of the first buffer and the furthest ones. These results are also confirmed by the analysis of investments per district.

Following the categories defined by Salzman et al. (2018), the “Adopt a green spot” PES scheme can be classified as a “user financed PES”, where users of generated ES pay the owners of the ES through a voluntary agreement. The PES scheme includes two different typologies of agreements. This characteristic allows defining a flexible scheme that facilitates the spread of the initiative over different typologies of stakeholders and in different areas of the city. The agreements defined, in fact, meet different needs of various stakeholder types. Citizens, condominium, universities, and local retailers join the initiative by adopting green areas within their neighborhoods through collaboration agreements to improve their aesthetic aspect, while companies prefer to adopt green areas located in the proximity of the city center choosing sponsorship agreements to gain public visibility and recognition. In fact, sponsorship agreement signed by firms are 87 (more than the 50% are concentrated nearby the city center) for a total of more than 1.700.000 € of commitment, that corresponds to 67% of total investments. Furthermore, peculiarities of this PES scheme design allow to generate relevant distributed social impacts. According to some authors (Barnaud & Antona, 2014), PES can improve the provision of services only in certain areas of the city. For example, land use planning for climate change adaptation have been found to exacerbate socio-spatial inequalities (Anguelovski et al., 2016; Kabish et al., 2015; Wen et al., 2013). The considered agreements, in particular the collaboration one, allow access to PES to various stakeholders with different economic capability (including individual citizens). Interventions are spread around different districts, with almost 70% of agreements located in residential districts. The cost to join the initiative vary according to several aspects, such as the dimension of the areas and the restoration and maintenance project. This allows a wide variety of stakeholders to be involved, also fostering restoration and management of marginal and residual green areas located in peripherical zones, thus enhancing the ES generated in these areas. Furthermore, the ability to attract numerous stakeholders is to be attributed to the low transaction costs of the PES scheme. Transaction costs in PES can be relevant because of the multiple ES provided by green areas and the number of stakeholders benefitting from these services. In this case, the standardization of the agreements and the flexibility in the modality to join it constitute a key element in keeping transaction cost at low level, so favorizing the replication of the scheme. In this case transaction costs are limited to the project design in the application phase to access the initiative. All other transaction costs are borne by the Municipality. It must be emphasized that the cost of implementation and management of green areas – in average 25,6 €/m2 - does not fully represent the social value produced by ES generated by green areas. In fact, green areas generate several ES at the urban scale (Croci et al., 2021) as they are multifunctional and can address several urban challenges (Kabish et al., 2016; Raymond et al., 2017; Dorst et al. 2019; La Notte and Zulian, 2021). Functioning ecosystems allow cities to build adaptive capacities and cope with several urban challenges, providing several ES, including reduction of local air pollution, microclimatic regulation (heat island phenomenon reduction and temperature increase due to climate change), direct health benefits, such as a lower prevalence of asthma in early childhood), mortality reduction, and general health improvements, flood risk reduction, quality of life improvement, social inclusion, safety and cultural benefits (Barò et al., 2014; Elmqvist et al., 2016; Emilsson and Ode Sang, 2017; Seddon et al., 2020; Croci and Lucchitta, 2021).

The main ES category valued through this PES is the cultural one and more precisely the aesthetic appreciation since stakeholders decide to take part in the initiative to improve the aesthetic aspect of their neighborhoods. Other ES such as air quality improvement, flood risk reduction, climate regulation are not accounted for. In fact, the social value includes the total economic value generated by all the ES which should be measured and valued individually. The social value generated also includes the regeneration and improvement of the different areas of the city (Andreucci, 2021). The green areas under the initiative are spread all over the city with a major concentration in the residential districts (almost 70%). Furthermore, most adopted green areas can be considered marginal and residual; in fact, 65% of adopted areas range between 1 and 200 m^2 of extension. The recovery and maintenance of these areas generate widespread benefits that affect various stakeholders and not just those who participate in the agreements.

The initiative has brought out the awareness of citizens regarding the relevance of the amount and quality of urban nature, and their interest in contributing to its maintenance. While the investments provided by different stakeholders in different areas can depend on several factors, including income, values, beliefs, cultural elements, and even returns in terms of public image, these determinants are not analyzed in this study and can constitute area for further investigation. Moreover, the different amounts of investment per areas don't represent an estimation of the different WTP of stakeholders to maintain green areas, as only one ES is considered, i.e., aesthetic appreciation, and because the requirements and economic contribution for involved stakeholders are pre-determined in standard agreements. Also, beneficiaries of green areas go beyond the involved neighborhoods, as such a diffuse presence of well-maintained green areas provides diffuse benefits spread to all citizens and city users. So financial resources provided for these agreements represent a strong underestimation of WTP to manage and maintain green areas in an urban context. A recent literature on WTP for ES has developed, individuating drivers such as income (Jacobsen and Hanley, 2009; Jacobsen et al., 2013; Schläpfer, 2006), living conditions, location of the valuators (Tait et al., 2012) and their beliefs, opinions and attitudes (Kotchen and Reiling, 2000; Boxall and Adamowicz, 2002; Dupont and Bateman, 2012). This is particularly important for ES in urban areas because of the implicit diversity in the population (Sato et al., 2017). Moreover, cultural ES are primarily driven by human experience, and this makes them harder to quantify (Chan et al., 2012).

Despite this, Milan administration has been able to involve different stakeholders to manage and maintain green areas, frequently marginal because of their size and location, collecting resources from private stakeholders and generating positive externalities perceived by all citizens.

The "Adopt a green spot" initiative represents a model urban PES scheme, already replicated more the more than 500 in the Milan Municipality and suitable to be replicated in other cities thanks to its design characteristics based on standard components and appealing to a variety of stakeholders. The main replicable elements enabling the success of scheme are i) flexibility of the voluntary agreements designed in order to meet the needs of various stakeholders; ii) variety of green areas included in the initiative (in particular the prevalence of small size areas allows the participation of stakeholders with low economic capacity); iii) public recognition through an advertising plate which makes possible to attract business actors; iv) low transaction costs borne by stakeholders who decide to join the initiative. Standardization allows overcoming relevant barriers related to the implementation of PES at urban scale, such as high transaction costs and different socio-cultural background of stakeholders. and facilitates the management of large number of contracts reducing administration costs for the Municipality.

6 Conclusion and implications for further research

Abstract
The section discusses the contribution of the thesis.

6.1 Thesis outcomes and contribution

NBS can help increase the amount and quality of green space to ensure benefits to different groups of citizens (Cortinovis and Geneletti, 2018) through the generation of ES at different scales. The study of ES in the urban environment is emerging as an important research frontier (Kremer et al., 2016). In particular, the inclusion of ES knowledge in urban spatial planning processes can contribute to highlighting existing needs, to defining standards and policy targets to support the selection and fine-tuning of alternatives (Cortinovis and Geneletti, 2018). NBS reinforce the idea that ES can be locally produced in urban areas to support human well-being in tangible and intangible ways. Considering the multifunctionality of NBS at the urban scale, their implementation requires a systemic approach that can consider the interactions between different dimensions: environmental, social, and economic. It is, therefore, necessary to identify ad hoc systems for monitoring the impacts, valuing the benefits generated, and adopting policy instruments that can maximize benefits generated by NBS and at the same time ensure their equitable distribution.

In light of this, the thesis analyzes and assesses methodologies and policy instruments to foster NBS implementation and management at the urban scale. The aim is to identify the main drivers for the implementation of urban NBS, taking into consideration how they impact the social value of generated ES. For this purpose, the thesis investigates i) assessment methodologies to measure the impacts generated by ES provided by NBS; ii) approaches to value these impacts considering their social, economic, and environmental dimensions and, iii) instruments that can be adopted to foster the implementation of NBS with a particular focus on PES schemes. The thesis provides elements useful to improve the planning and implementation of NBS. More in detail, it identifies and systematizes approaches for measuring the impacts generated by urban NBS using an ES-based approach. Furthermore, the thesis identifies and assesses methodologies that can be adopted for the economic evaluation of ES produced by urban NBS. Finally, the application of an innovative instrument - PES - for the implementation of NBS at urban scale is analyzed through a specific case, highlighting the elements that can facilitate its replication in different contexts.

As emerged from the review of the literature performed in Chapter 1, green areas generate several ES at the urban scale as they are multifunctional and can address several urban challenges. Functioning ecosystems allow cities to build adaptive capacities and cope with several urban challenges, providing several ES, including reduction of local air pollution, microclimatic regulation (heat island phenomenon reduction and temperature increase due to climate change), direct health benefits, such as a lower prevalence of asthma in early childhood), mortality reduction, and general health improvements, flood risk reduction, quality of life improvement, social inclusion, safety, and cultural benefits. The lack of adequate evaluation implies the underestimation of these benefits, and also of possible trade-offs (Chapter 1). Enhancement of NBS can have significant social implications, which are often overlooked by policymakers (Haase et al. 2017), exacerbating already existing social inequalities if access to green space is exclusively improved for those wealthy enough to afford to live in proximity to these environmental amenities or if green spaces are conceived without attending to specific contextual needs (Anguelovski 2016; Curran and Hamilton 2018). Measuring impacts requires the definition of a monitoring system that considers co-benefits and trade-offs within and across the stages of implementation (Chapter 2). The assessment of impacts is in many cases restricted to single challenge areas (e.g., biodiversity, climate regulation, flood risk reduction, etc.) and rarely addresses cross-sectoral impacts (e.g., links between biodiversity and the economy). An ES-based approach can provide a framework to assess the overall contribution of NBS to society and monitor it over time. The definition of a framework based on the ES approach is only the first step. The concrete application of such a framework requires overcoming complex issues and targeting specific methodologies and instruments to real contexts. The complexity of urban environments (considering environmental, cultural, social, and economic aspects) and the interactions between many ES requires a holistic perspective to ensure that values generated by NBS implementation can be adequately accounted and allocated. The adoption of KPIs and monitoring procedures at the urban scale is not straightforward. Impact evaluation is an essential part of a broader agenda of evidence-based policy-making and is pivotal to building knowledge about the effectiveness of interventions to achieve desired change (Morton 2009). It is therefore essential to estimate in advance what impacts (or effects) an NBS intervention is expected to have, so that appropriate data at the appropriate scale (e.g., spatial and temporal) may be collected (Morton, 2009). Performance can be assessed by comparing against baselines before NBS implementation, different NBS interventions, or alternative non-NBS interventions including trends over time (Dimitru et al., 2021). Impact evaluation of NBS interventions requires a joint effort of different actors to be able to assess a wide range of outcomes and identify trade-offs before, during, and after NBS implementation. However, evaluation processes may face different challenges such as data availability, access to resources, capacity building, etc.

The assessment of NBS impacts is also fundamental to facilitate the economic valuation of the related benefits. In fact, value generated by ES at the urban level is generally underestimated. Lack of consideration of full economic value of ES generated by NBS can incentivize undesirable conversion of ecosystems into built infrastructures, with associated loss of ES. As emerged from the analysis (Chapter 3), not all ES are correctly valued through available methodologies, therefore there is a need to improve capacity of valuation methodologies to fully capture the total value of all ES provided by a natural resource. A critical aspect refers to the difference in values estimated using different methodologies. In fact, valuation methodologies show different levels of appropriateness with respect to specific ES categories. A possibility to provide more reliable values of NBS is to use a combination of valuation models. Moreover, values of ES are often site-specific, as societal, and economic conditions of each context, including the characteristics of urban residents and in particular their economic status affect the values of ES following several methodologies, especially the ones based on the willingness to pay (e.g.: contingent valuation). The integration with other assessment approaches such as mapping of the status of ES can help to overcome some of the barriers and biases encountered in the economic valuation of ES. In fact, ES mapping can be used to investigate how ES values vary across space and to identify spatial areas with high or low provision and high or low demand for ES. This can also compensate the socio-cultural drivers affecting the perception and the value attribution of nature by different stakeholders.

The monetary valuation of ES is traditionally absent from economic accounting so that their production ordinarily fails to reach social optimum conditions. As a result, their critical contributions are not considered in public, corporate, and individual decision-making. The valuation of ES benefits allows to price the impacts generated by human action on the environment, so to disclose the complexity of human-environment relationships highlighting how human decisions affect the flows and the values of ES. This would foster the introduction of policies and actions which protect and enhance ES though the implementation of NBS. Attaching a value to environmental goods would make it easier for their inclusion in economic choices and public decision-making processes. Eventually, this will lead to the creation of stronger conservation policies, and to the adoption of economic instruments that would result in a better safeguard of the environment. Economic valuation can shed light on the multifunctionality of ES generated by NBS at the urban level, thus allowing to capture their value. In fact, the enhancement of NBS at the urban scale requires to capture the value created by them.

Value creation refers to the production of social, environmental, and economic benefits geared towards specific end-users through activities, channels, and partners. Value capture refers to the capacity to internalize benefits generated, it is about considering how to "earn revenues" from the provision of good, services and information. Economic instruments can allow incorporating the values of ecosystems into decision making, through economic incentives/disincentives and price signals. At this purpose, PES aim to stimulate the production of positive externalities. In fact, PES are defined as "voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services". PES schemes allow service buyers to pay for the safeguard of a natural resource and the services it provides on which they are reliant, hence preventing the risk it becomes scarce, and to compensate for the negative externalities caused by production or consumption activities to the society (UNEP, 2009). In this way, it is possible to change those behaviors which harm ecosystems (Rojas and Aylward, 2003). Chapter 4 and Chapter 5 highlight some positive impacts and shortcomings of PES adoption at the urban scale. The "Adopt a green spot" case study highlights how PES have proven to be suitable for the implementation of NBS and for the engagement of different stakeholders in the sustainable management of ecosystems, but the complexity of urban environments and the interactions between many ES require a holistic perspective to ensure the optimal generation and distribution of benefits. Based on results it has been possible to identify the main elements that enabled the success of the PES in the Milan municipality. First, the high flexibility given to the prosed scheme made it possible to meet the needs of various stakeholders (from firms to single citizens). Second, the rewarding mechanism linked to the public recognition allowed to attract firms' investments in different areas of the city with a particular concentration in the central ones. Finally, the variety of green areas (considering areas of different dimensions but also of different typologies) included in the initiative, facilitated the attraction of stakeholders with low economic capacity in the management of marginal green areas. These elements in the policy design brought out the awareness of citizens towards environmental issues for the enhancement of urban green areas and their willingness to contribute to maintain and manage them. All in all, the city government has been able to involve different stakeholders to manage and maintain green areas, frequently marginal because of their size and location, collecting resources from private stakeholders and generating positive externalities perceived by all citizens. It is fundamental to highlight the importance of local governments in defining a framework and structuring rules, conditions, payments, and stakeholders' involvement in PES schemes.

A critical aspect of PES application is the inclusion of different ES categories in the scheme. The main ES category valued by the Milanese PES scheme is the cultural one and more precisely the aesthetic appreciation since stakeholders decide to take part in the initiative to improve the aesthetic aspect of their neighborhoods. Other ES such as air quality improvement, flood risk reduction, climate regulation are not accounted for. In fact, social value includes the total economic value generated by all the ES which should be measured and valued individually. Green areas under the initiative are spread all over the city with a major concentration in residential districts. Furthermore, most of green areas that have been adopted can be considered marginal and residual. The recovery and maintenance of these areas generated widespread benefits that affect various stakeholders and not just those who joined the initiative.

Cultural ES in particular can play an important role in the improvement of urban spaces and well-being. Despite this, their importance is often overlooked during urban planning (Ahmed et al. 2019). Incorporating cultural ES into urban planning and policy-making could help to increase awareness of nature as a critical component of human health and well-being. Previous research identified a connection between cultural ES and public engagement (Colding and Barthel 2013, Andersson et al. 2014, Gould et al. 2014, Chakraborty et al. 2020). Individuals and communities prefer to support actions when those actions improve cultural ES (Dendoncker et al. 2013, Andersson et al. 2015). Furthermore, the engagement of people in cultural ES stewardship could increase the awareness of these benefits for a larger group of non-cultural urban ES since cultural ES are often generated interdependently from other critical ES (Milcu et al., 2013, Jennings et al., 2016).

Different studies (Dorste et al., 2017; Sarabi et al., 2019) considered market-based instruments as enablers for NBS adoption at urban scale. Despite this, according to Hawxwell et al. (2019), economic instruments may also represent a barrier for NBS implementation, depending on how they are formulated. In fact, market-based instruments should be tailored to the local environment and conditions, creating a realistic, attractive, and viable context for the adoption of NBS. Doubts are voiced due to the multiple and complex conditions for economic instruments to actually work in specific socio-cultural and legal contexts (Vatn 2010, Lockie 2013); some authors caution against an over-reliance on "win-win" solutions and PES schemes as panacea (Muradian et al 2013). Despite this, by tackling imbalances in "who benefits from nature's services" and "who bears the costs to maintain or enhance them", economic instruments are essentially a means to re-allocate resources and lead to a more just distribution. In this sense the economic approach can go beyond merely demonstrating societal benefits from ES through valuation, but rather identifies opportunities to change behavior of involved actors to successfully and verifiably enhance ES benefits. A well-designed PES can ensure the participation of different stakeholders in NBS management and ES protection also avoiding the exacerbation of socio-spatial inequalities (Anguelovski et al., 2016; Kabish et al., 2015; Wen et al., 2013). In fact, PES are mechanisms that can capture the social values generated by ES and to redistribute them equally. Effective land use management practice should ensure that value of land, a finite natural resource, benefits all citizens, particularly when investments in new infrastructures - such as NBS - can produce social inequalities (e.g., increase property values in particular areas of the city). To successfully address today's urban development challenges, policy-makers should be equipped with effective and sustainable land use management tools to promote more equitable distribution of resources. Value capture instruments - such as PES - offer opportunities through which local governments can generate revenues consequent to investments in NBS to be redistributed to less affluent areas in the city. In urban areas, the scarcity of affordable, well-located land poses a major obstacle to the provision of adequate services in different areas of the city. Value creation is important because it can potentially create a "surplus" that thanks to the use of value capture mechanisms can cross-subsidize the improvement of degraded urban areas. Value creation is the production of social, environmental, and economic benefits generated thought the implementation of a service or a product – in this case ES generated by urban NBS. When used in conjunction with sound governance and urban planning principles, PES can be a useful tool to help governments advance positive social, and environmental outcomes.

Research outcomes contribute to setting the stage for the development of further investigations aimed to identify assessment frameworks that can be applied at the urban level to evaluate ES and to measure impacts provided by NBS considering social, environmental, and economic dimensions. The impact assessment and the economic valuation of ES at the urban scale is a relatively new research topic that has only developed in recent years and therefore available literature is limited. The analysis sets the stage for the development of further investigations aimed to standardize valuation methodologies that can be applied at the urban level to value ES. The work also recognizes the complexity of the multiple co-benefits of NBS, the interaction between them and the possible synergies and trade-offs. It suggests more work on standardization of methods on one side, but it also calls for site-specific approaches. In particular, the social value of NBS and the perception of ES impacts based on the socio-cultural backgrounds could be further investigated to improve the design and planning of context based NBS. Furthermore, the identification of social and public value through surveys or other approaches (e.g., ES mapping) – involving different stakeholder - could also allow to improve the design and implementation of local PES schemes.

The thesis shows that innovative approaches for the assessment and economic valuation of NBS impacts at the urban scale are available. Furthermore, policies and instruments that can be adopted to foster the implementation of NBS have been proven to be efficient. The PES scheme analyzed allows to implement and manage NBS through the involvement of both private and public stakeholders. Their involvement can represent an important issue to avoid the exacerbation of social inequalities that can be linked to the spatial distribution and the allocation of benefits related to urban green spaces planning. The analysis highlights also that it is necessary to identify a holistic approach that allows considering benefits generated by NBS at the urban scale and to properly value them. This can facilitate the integration of different sectoral policies and different levels of governance involved in the enhancement of the ES and allows for the consideration of multiple functions of ES provided by NBS at the urban scale. In fact, the concept of NBS embodies a vast interdisciplinary dialogue (Brown, 2013; Miller et al., 2008; Olsson et al., 2014) and acts as catalyst for several pressing concerns in global environmental change (Brand and Jax, 2007; Meerow et al., 2016; Newell and Cousins, 2015). The process for NBS planning and implementation needs to create just and equitable outcomes instead of increasing socio-spatial inequality. The implementation of NBS requires the adoption of different instruments that can be integrated in urban planning approaches to create a policy mix capable of enhancing and protecting services provided by ecosystems, tackling social and environmental challenges based on the specific needs of each territory and context.

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Appendix I

CHALLENGES	TYPE OF INDICATORS	KPI	SCALE R=Regional M=Metropolitan U=Urban S=Street B=Building	ECOSYSTEM SERVICES
CHALLENGE 1: Climate mitigation & adaptation	Carbon savings per unit area (environmental, chemical) Carbon storage and sequestration in vegetation and soil (Davies et al., 2011; Demuzere et al., 2014).	Tonnes of carbon removed or stored per unit area per unit time (Zheng et al., 2013), total amount of carbon (tonnes) stored in vegetation (Davies et al., 2011).	>R	Regulation
		Comparison with calculations of carbon consumption of equivalent non-NBS actions (e.g. through Life Cycle Assessment).	>R	Regulation
		Allometric forest models of carbon sequestration, developed using proxy data obtained from Lidar data (Giannico et al., 2016).	>R	Regulation
		Growth rates derived from Forest Inventory Analysis (Zheng et al., 2013).	>R	Regulation
	Carbon savings per unit area (economic) Value of carbon sequestration by trees (Baró et al., 2014).	Measurements of gross and net carbon sequestration of urban trees based on calculation of the biomass of each measured tree (i-Tree Eco model), translated into avoided social costs of CO2 emissions (USD t-1 carbon).	>R	Regulation
	Temperature reduction (environmental, physical)	Decrease in mean or peak daytime local temperatures (oC) (Demuzere et al., 2014).	R M U	Regulation
		Measures of human comfort e.g. ENVIMET PET — Personal Equivalent Temperature, or PMV — Predicted Mean Vote.	R M U	Regulation
			R M U	Regulation

		Heatwave risks (number of combined tropical nights (>20oC) and hot days (>35oC)) following Fischer, Schär, 2010, cited by Baró et al. (2015).		
	Energy and carbon savings from reduced building energy consumption (environmental, physical)	kWh/y and t C/y saved.	R M U	Regulation
		Final Energy Consumption		Regulation
		Final Energy use/capita		Regulation
		use of Star tools to calculate projected maximum surface temperature reduction	M, U	regulation
		physical measurement of temperature in the demo sites	M, U, S, B	regulation
		use of GI Val to calculate carbon savings from GI providing shade, shelter, reduction in water treatment etc	U,S,B	regulation
CHALLENGE 2: Water Management	Physical indicators	Run-off coefficient in relation to precipitation quantities (mm/%) (Armson et al., 2013; Getter et al., 2007; Iacob et al., 2014; Scharf et al., 2012)	R M U S B	Regulation
		Flood peak reduction (Iacob et al., 2014), Increase in time to peak (Iacob et al., 2014) (%).	R M U S	Regulation
		Reduction of drought risk (probability).	RM	Regulation
		Increasing ground water availability, (depth to groundwater) (Feyen and Gorelick, 2004).	R M	Supporting
		Absorption capacity of green surfaces, bioretention structures and single trees (Armson et al., 2013; Davis et al., 2009)	S B	Supporting
		Increased evapotranspiration measured/modelled (Litvak and Pataki, 2016).	R M U S B	Regulation
		Temperature reduction in urban areas (°C, % of energy reduction for cooling) (Demuzere et al., 2014).	RMUS	Regulation
		Soil water storage capacity (mm)		Regulation
		Soil water infiltration capacity (cm)		Regulation

		Water retention capacity by vegetation and soil (ton km-2)		Regulation
		Intercepted rainfall (m3 year-1)		Regulation
		Share of green areas in zones in danger of floods (%)		Regulation
		Population exposed to flood risk (% per unit area)		Regulation
		Areas (ha) and population exposed to flooding		Regulation
	Chemical indicators (water quality)	Nutrient abatement, abatement of pollutants (%, nutrient load, heavy metals).	R	Regulation
		Increase of ground water quality (nutrient load, heavy metals).	R	Regulation
		Water Quality Index for Biodiversity		Provisioning
		Drinking water provision (m3 ha-1year-1)		Provisioning
		Water for irrigations purposes (m3 ha-1year-1)		Provisioning
	Economic indicators (benefits)	Economic benefit of reduction of stormwater to be treated in public sewerage system (€) (Deng et al., 2013; Soares et al., 2011; Xiao and McPherson, 2002)	R M U	Regulation
		Reduction of inundation risk for critical urban infrastructures (probability) (Pregnolato et al., 2016)	RMUSB	Regulation
		Stage-damage curves relating depth and velocity of water to material damages (€) (de Moel et al., 2015).	RMUSB	Regulation
		volume of water removed from water treatment system	U, S, B	Regulation
		volume of water slowed down entering sewer system	U,S,B	Regulation
CHALLENGE 3: Coastal Resilience	**Physical indicators** (Fagherazzi, 2014; Gedan et al., 2011; Grabowski et al., 2012; Stark et al., 2016).	Shoreline characteristics and erosion protection	R M	Regulation
		Soil, temperature, drainage	U	Regulation
		Flooding characteristics	U	Regulation
		Avoided damage costs	U S B	/

	Economic indicators (Gedan et al., 2011; Narayan et al., 2016; Shuster and Doerr, 2015).	Changes in property value	S B	/
	Social and education indicators (Piwowarczyk et al., 2013; Schuster & Doerr, 2015).	Recreation and public access	M U	Cultural
		Number of students benefiting from education and research about coastal resilience/amenity	R	Cultural
	Biological indicators (Bell, 1997; Yepsen et al., 2016).	Estimates of species, individuals and habitats distribution	R M	Supporting
		Invasive and planted species	R M U	Supporting
		Algal bloom	R	Supporting
	Chemical indicators (Grabowksi et al., 2012; Yepsen et al., 2016).	Concentration of nutrients	U S	Regulation
		Salinity, pH	U S	Supporting
CHALLENGE 4: Green Space Management	Social indicators (benefits)	Distribution of public green space – total surface or per capita (Badiu et al., 2016; Gómez-Baggethun and Barton, 2013; La Rosa et al., 2016).	R M U	Cultural
		Accessibility (measured as distance or time) of urban green spaces for population (Tamosiunas et al., 2014).	R M U S	Cultural
		Recreational (number of visitors, number of recreational activities) or cultural (number of culturalevents, people involved, children in educational activities) value (Kabisch and Haase, 2014).	R M U S	Cultural
		Percentage of people living within 300 m of green urban areas of any size in inner city		Cultural

		Accessibility15 to public parks, gardens and play-grounds (more than 50 ha) - (inhabitants within 10 km from a park)		Cultural
		Accessibility to public parks gardens and play-grounds (between 10 ha and 50 ha) - (inhabitants within 1 km from a park)		Cultural
		Accessibility to public parks gardens and play-grounds (between 2.5 ha and 10 ha) - (inhabitants within 500 m from a park)		Cultural
		Accessibility to public parks gardens and play-ground (between 0.75 ha and 2.5 ha or smaller but important green spaces) - (inhabitants within 250 m from a park).		Cultural
		Weighted recreation opportunities provided by Urban Green Infrastructure (Derkzen et al. 2015)		Cultural
		Nature based recreation opportunities (includes Natura 2000; includes bathing water quality) (dimensionless) (Zulian et al. 2013)		Cultural
		Proximity of green infrastructure to green travel routes (km)		Cultural
		Green related social service provided to population (dimensionless) (Secco and Zulian 2008)		Cultural
		Accessibility of parks from schools (number of public parks and gardens within a defined distance from a school)		Cultural
	Environmental (biological)	Changes in the pattern of structural and functional connectivity (Iojă et al., 2014).	R M U	Supporting
		Species richness and composition in respect to indigenous vegetation and local/national biodiversity targets (Cohen et al., 2012; Krasny et al., 2013).	R M U S B	Cultural
		15.1.1 Forest area as a proportion of total land area		Supporting
		15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type		Supporting
		Biodiversity Habitat Index		Supporting

		Trends in land degradation (proposed for SDG target 15.3)		Supporting
		Number and total area of designated sites of local (city) biodiversity importance within the city (habitat/species management areas)		Supporting
		Number and total area of Natura 2000 sites that are located in the city or nearby (i.e. within 10 km)		Supporting
		Production of food (ton ha-1 year-1)		Provisioning
		sustainability of green areas		
		quality of life for elderly people		Cultural
		Increased connectivity to existing GI	M,U.S	Supporting
		Pollinator species increase	U, S,	Supporting
CHALLENGE 5: Air Quality	Environmental (chemical)	Non-spatial indicators of gross quantities: annual amount of pollutants captured by vegetation (Bottalico et al., 2016).	R M U S	Regulating
		Non-spatial indicators of net quantities: net air quality improvement (pollutants produced – pollutants captured + GHG emissions from maintenance activities) (Baró et al., 2014).	M U S	Regulating
		Non-spatial indicators of shares: share of emissions (air pollutants) captured/sequestered by vegetation (Baró et al., 2014).	M U S	Regulating
		Spatial indicators: pollutant fluxes per m2 per year (Manes et al., 2016; Tallis et al., 2011).	M U S	Regulating
		11.6.2 Annual mean levels of fine particulate matter (e.g. PM2.5 and PM10) in cities (population weighted) oncentration recorded ug/m3		Regulation
		Trends in emissions NOX, SOX		Regulation
		Trends in CFC emissions (chlorofluorocarbons (CFCs) in ODP		Regulation

		Mean levels of exposure to ambient air pollution (population weighted) (proposed indicator for SDG target 3.9)		Regulation
		Pollutants removed by vegetation (in leaves, stems and roots) (kg ha-1 year-1)		Regulation
	Economic	Monetary values: value of air pollution reduction (Manes et al., 2016); total monetary value of urban forests including air quality, run-off mitigation, energy savings, and increase in property values (Soares et al., 2011). use of GI val to calculate the value of air quality improvements	M U	/
	Social (physiological)	Other indicators: health impact indicators such as premature deaths and hospital admissions averted per year (Tiwary et al., 2009).	R M U	Supporting
		Number of deaths from air, water and soil pollution and contamination (proposed indicator for SDG target 3.9)		Supporting
		11.5.1 Number of deaths, missing persons and persons affected by disaster per 100,000 people		Supporting
		air quality parameters Nox, VOC, PM etc		Regulation
CHALLENGE 6: Urban Regeneration	Urban green indicators (environmental, biological)	Urban green: Index of biodiversity, provision and demand of ecosystem services.	R M U S B	Supporting
		Ecological connectivity (Pino and Marull, 2012).	R M U	Supporting
		Accessibility (Schipperijn et al., 2010): distribution, configuration, and diversity of green space and land use changes (multi-scale; Goddard et al., 2010).	R M U	Cultural
		Ratio of open spaces to built-form.	S B	Cultural
		Reclamation of contaminated land: percentage of contaminated area reclaimed.	U S B	Regulating
		Reclamation of building materials: percentage reclaimed from existing buildings.	B	/

	Building efficiency and environmental design indicators	Energy efficiency: building materials/construction methods based on points awarded according to energy efficiency checklist.	B	/
		Incorporation of environmental design: percentage of total building stock.	B	/
		Land devoted to roads: percentage of site area occupied by roads.	R M U S	/
	Socio-cultural indicators	Conservation of built heritage resources: percentage of built from retained for culture.	B	Cultural
		Land dedicated to pedestrians: percentage of road network.	R M U S	Cultural
		Public transport links: walking distance to nearest facilities.	U S	Cultural
		Access to open space: average journey time for residents/employees by foot or average distance to sports centre, recreation area, or green space.	M U S	Cultural
		Access to cultural facilities: average journey time for residents on foot or average distance to cultural centre.	M U S	Cultural
		Access to housing: affordability and choice.	R M U	Cultural
		Level of devices contributing to the safety of users in the neighbourhood: lighting of common areas, access control, presence of technical, or specialized staff, etc.	B	Cultural
		assessment of typology, functionality and benefits provided pre and post interventions		/
		savings in energy use due to improved GI		Regulation
CHALLENGE 7: Participatory Planning and Governance	Social	Openness of participatory processes (Frantzeskaki and Kabisch, 2016; Luyet et al., 2012; Uittenbroek et al., 2013).	R M U S	Cultural
		Legitimacy of knowledge in participatory processes (Frantzeskaki and Kabisch, 2016; Luyet et al., 2012).	R M U	Cultural

		Social learning concerning urban ecosystems and their functions/services (Colding and Barthel, 2013).	R M U S	Cultural
		Policy learning concerning adapting policies and strategic plans by integrating ecosystem services and possibly their valuation (Crowe et al., 2016; Uittenbroek et al., 2013; Vandergert et al., 2015).	R M U S B	Cultural
		Perceptions of citizens on urban nature (Buchel and Frantzeskaki, 2015; Colding and Barthel, 2013; Gerstenberg and Hofmann, 2016; Scholte et al., 2015; Vierikko and Niemelä, 2016).	R M U	Cultural
		Social values for urban ecosystems and biodiversity (Brown and Fagerholm, 2014; Kenter et al., 2015; Polat and Akay, 2015; Raymond et al., 2014, 2009; Scholte et al., 2015).	R M U	Cultural
		citizen participation in the development and delivery of interventions		Cultural
CHALLENGE 8: Social Justice and Social Cohesion	**Social justice,** informed by the capability framework of social justice (Comim et al., 2008; Nussbaum, 2011; Sen, 2005).	Access to financial resources, including indicators of income per capita in a given neighbourhood, or urban area (Klasen, 2008).	U S	/
		Bodily integrity - Being able to move freely from place to place; to be secure against violent assault, including indicators of crime by time of day (Felson and Poulsen, 2003).	S B	Cultural
		Senses, imagination and thought: being able to use the senses, to imagine, think, and reason about the environment, informed by indicators of levels of literacy, mathematics and science knowledge (Chen and Luoh, 2010; Elliott et al., 2001).	S B	Cultural
		Emotions: being able to have attachments to things and people outside ourselves; to love those who love and care for us, including indicators of place attachment, empathy and love (Lawrence et al., 2004; Manzo and Devine-Wright, 2014; Perkins et al., 2010; Raymond et al., 2010).	U S B	Cultural
		Being able to participate effectively in political choices that govern one's life, including indicators on level and quality of public participation in environmental management (Reed, 2008; Reed et al., 2009).	R M U S B	Cultural

		crime reduction through police reports and local authority data	U,S,B	Cultural
		11.7.1 Average share of the built-up area of cities that is open space for public use for all, by sex, age and persons with disabilities		Cultural
	Social cohesion	Structural aspects: indicators of family and friendship ties; participation in organised associations; integration into the wider community (Cozens and Love, 2015; Stafford et al., 2003).	S	/
		Cognitive aspects: indicators of trust, attachment to neighbourhood, practical help, tolerance and respect (Mihaylov and Perkins, 2014; Uzzell et al., 2002).	S	Cultural
		green intelligence awareness		Cultural
CHALLENGE 9: Public Health and Well-being	**Psychological indicators** (Relaxation and restoration, sense of place, exploratory behaviour, socializing).	Noise reduction rates applied to UGI within a defined road buffer dB(A) m-2 vegetation unit (Derkzen et al. 2015)		Regulation
		Reduction in chronic stress and stress-related diseases measured through repeated salivary cortisol sampling (Roe et al., 2013; Ward Thompson et al., 2012) and hair cortisol (Honold et al., 2016); use cortisol slope and average cortisol levels as an indicator of chronic stress.	U S B	Cultural
		Cognitive and social development in children: indicators related to improvement in behavioural development and symptoms of attentiondeficit/hyperactivity disorder (ADHD) related to green space use; questionnaire indicators on sociodemographic and household characteristics, the time spent playing in green and blue spaces, ADHD symptom criteria, such as emotional symptoms, inattention, conduct problems, hyperactivity/inattention, and peer relationship problems; and a strengths subscale for prosocial behaviour (Amoly et al., 2014).	U S B	Cultural
			U S B	Cultural

		Mental health changes measured through Mental Well-being scales asking participants how they have felt over the previous four weeks in relation to a number of items (e.g., feeling relaxed, feeling useful), with responses rated on a 5-point scale from "none of the time" to "all of the time" (Roe et al., 2013).		
	Health indicators related to physical activity (Sports and leisure activities including e.g. walking, cycling).	Number and share of people being physically active (min. 30 min 3 times per week).	U	Cultural
		Reduced percentage of obese people and children; reduced overall mortality and increased lifespan.	U	Cultural
		Reduced number of cardiovascular morbidity and mortality events (Tamosiunas et al., 2014).	U	Cultural
	Health indicators related to ecosystem service provision (Buffering of noise and air pollution, reduced heat, exposure to microflora).	Reduced autoimmune diseases and allergies (potentially) (Kuo, 2015).	U	Cultural
		Reduced cardiovascular morbidity and mortality (Tamosiunas et al., 2014).	U	Cultural
		GIS related indicators: NDVI, proximity measures (green space of min. 2 ha within 300m, (Maas et al., 2006; Vries et al., 2003)), percentage of green space (Kabisch and Haase, 2014; van den Berg et al., 2010).	R M U S B	Cultural
		measurement of wellbeing of people in the area, employees and visitors		Cultural
		increase in walking and cycling in and around areas of interventions		Cultural
CHALLENGE 10: Potential of economic opportunities and green jobs	Economic	Number of subsidies or tax reductions applied for (private) NBS measures (Meulen et al., 2013).	R M U S B	/
		Number of jobs created (Forestry Commission, 2005); gross value added (Forestry Commission, 2005).	R M U	/
		Change in mean or median land and property prices (Forestry Commission, 2005).	R M U S B	/
		New businesses attracted and additional business rates (Eftec, 2013).	R M U	/

	Resource efficiency in the urban system (CO_2 emissions per capita, CO_2 emissions for transportation per capita, etc.) (OECD, 2013).	R M U	/
	Public-sector cost per net additional job (Tyler et al., 2013).	R M U	/
	Net additional positive outcomes into employment (Tyler et al., 2013).	R M U	/
	Net additional jobs (Tyler et al., 2013) in the green sector enabled by NBS projects.	R M U	/
	Gross value added per employees based on full-time equivalent jobs (Tyler et al., 2013) in the green sector.	R M U	/
	Production benefit: earnings uplift arising from skills enhancement (Tyler et al., 2013) in the design and implementation of NBS.	R M U	/
	Consumption benefits: property betterment and visual amenity enhancement (Tyler et al., 2013) resulting from NBS.	R M U	/
	job creation, increased footfall and spend in the areas of interventions if appropriate		Cultural