

Article

Urban Forests and Green Areas as Nature-Based Solutions for Brownfield Redevelopment: A Case Study from Brescia Municipal Area (Italy)

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Abstract: Urban areas are experiencing major changes and facing significant sustainability challenges. Many cities are undergoing a transition towards a post-industrial phase and need to consider the regeneration of brownfield sites. Nature-Based Solutions (NBSs) are increasingly considered as tools for supporting this transition and promoting sustainable development by delivering multiple ecosystem services (ESs). Although the potential of NBSs as a cost-effective enabler of urban sustainability has been recognized, their implementation faces numerous barriers. The effective assessment of benefits delivered by urban NBSs is considered by existing literature as one of them. In order to contribute to filling this knowledge gap, we analyzed two alternative NBS-based intervention scenarios—i.e., (1) an urban forest and (2) meadows with sparse trees—for the redevelopment of an urban brownfield area within the municipality of Brescia (Northern Italy). Nine ESs were assessed both in biophysical and economic terms via a combination of modeling (InVEST, i-Tree and ESTIMAP) and traditional estimation methods. The results show that both scenarios improve ES stock and flow compared to the baseline, ensuring annual flows ranging between 140,000 and 360,000 EUR/year. Scenario 1 shows higher values when single ESs are considered, while scenario 2 shows higher total values, as it also accounts for the phytoremediation capacity that is not considered under the first scenario. All in all, regulating ESs represent the bulk of estimated ESs, thus highlighting the potential of proposed NBSs for improving urban resilience. The ES assessment and valuation exercise presented within this paper is an example of how research and practice can be integrated to inform urban management activities, and provide inputs for future decision making and planning regarding urban developments.

Keywords: contaminated sites; economic valuation; ecosystem services; green infrastructure; NBS; urban green brownfields



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1. Introduction

Urban areas are experiencing major changes and facing significant environmental, social and economic sustainability challenges. On the one hand, the world is undergoing the largest wave of urban growth in history [1]. Urban areas have expanded in recent decades and so has the number of people living within them: more than half of the world's population now lives in towns and cities, and that proportion will continue to grow in coming decades [2]. At the same time, shrinking cities—i.e., densely populated urban areas that faced a population loss and are undergoing economic transformation (e.g., de-industrialization, internal migration), with some symptoms of a structural crisis—are becoming a common phenomenon in many regions, particularly in Europe, North America

and Japan [3]. Concerns about the sustainability of cities and urban areas have emerged accordingly [4,5], as witnessed by, among others, the 2030 Agenda for Sustainable Development; the latter includes Sustainable Development Goal 11, which aims to “Make cities and human settlements inclusive, safe, resilient and sustainable” [6]; the world Forum on Urban Forests [7]; and the UN New Urban Agenda [8]. Nature-Based Solutions (NBSs)—an emerging umbrella concept that incorporates different forms of nature-based (i.e., green) interventions [9]—can contribute to addressing ecological, social and economic sustainability challenges in urban areas [4,10,11]. Although there is not a univocal definition for NBSs and diverse perspectives on this concept have emerged [12,13], the term is increasingly integrated within policies and research activities, with a potential opening for transformational pathways towards sustainable societal development [14]. By supporting ecosystem processes and structures, such as the presence and features of a certain habitat (e.g., a forest, its species composition, and canopy characteristics), NBSs can deliver a broad range of ecosystem services (ES); these are ecosystem outputs in terms of material (e.g., wood for energy) and immaterial products and services (e.g., aesthetic view), targeting and benefiting various social groups and, ultimately, contributing to quality of life and people’s wellbeing [15–17]. The benefits of ESs can be understood as something that changes people’s wellbeing in terms of, for instance, health, security, or social relations [17]. These changes can be perceived as important by ES beneficiaries who, therefore, assign a value to them—in monetary and non-monetary terms—and, indirectly, to the ES and the ecosystem processes and the structures generating them [18].

NBSs can support the regeneration of neglected urban spaces. These include including brownfield sites (e.g., former residential, industrial, or infrastructural areas) [19,20] and urban green brownfields (i.e., vegetation-covered urban brownfields) [21,22] that would otherwise run the risk of being totally abandoned and exposed to further degradation, due to the high economic, environmental and social costs of traditional remediation techniques and technologies [23–26]. While these high costs may delay redevelopment projects [27], the persistence of brownfields triggers environmental degradation, economic decline and social exclusion; this generates potential risks to human wellbeing [28–30] and public health [31], as well as representing a key challenge for urban planning and development [32].

On the contrary, the conversion of brownfields into new green spaces and valuing of urban green brownfields through the development of effective NBSs can deliver multiple ESs [33,34]; this has the potential to bring social, environmental and economic benefits to local communities [25]. Many studies found that urban NBSs, particularly green areas, can play a central role in quality of life in cities [35–38], contributing to citizens’ wellbeing [39,40] and improving their physical and mental conditions [25,41–43]. They provide space for recreation, sport activities and healthier lifestyles [37,44,45]; offer educational opportunities; offer possibilities for interactions and social inclusion; and reinforce cultural identities and aesthetic value [46]. They can also enhance social equality by improving environmental conditions for people living in deprived communities [47]. The redevelopment of sites using NBSs can be effective at protecting, providing or enhancing regulating ESs; for example, it can contribute to the absorbing air pollutants [48]; sequestering CO₂; lowering the temperature within cities [49]) and in the surroundings [50,51]; reducing noises [52,53]; and improving flood control and water resource management [54], as well as water treatment [55]. NBSs can prevent natural hazard and climate extremes while contributing to climate change mitigation [56], and can sustain or enhance biodiversity [14,57–59].

Overall, NBSs can contribute to improving the resilience of urban systems [16,60], generating economic benefits long term, and creating healthier local economies [61]. It has been claimed that they are more cost-effective than traditional grey solutions [10,12,62,63] however, there are still barriers to their implementation and upscaling. A substantial challenge is represented by full valuation of the ESs they deliver because of methodological gaps and a lack of standardized metrics [56]. Moreover, data to assess complex ESs are not always available or easy to access, and conventional valuation and accounting practices do not normally include these benefits [64]. As a consequence, ES production by NBSs is

not considered in public, corporate, or individual decision making [65,66]. Existing studies tend to focus on one or few specific ESs delivered by a single NBS, rather than grasping the value of a broad range of benefits being co-delivered or considering possible trade-offs and synergies between them [39]. This is connected to the fact that while the literature on ES assessment has grown in recent years, and despite an emerging interest in ESs provided by urban ecosystems and their components [15,67,68]), ES valuation applied to urban contexts is still limited [66]. A better understanding of the economic value generated by NBSs, and the ESs they provide, could facilitate the adoption of efficient policies and measures to preserve and enhance them [15,69]. It could also function to raise stakeholders' awareness and participation in decision making processes [70], and would help in supporting the inclusion of NBSs within urban planning [16,56], including in brownfield redevelopment projects [56,71]. However, there is still a lack of cases demonstrating the support of ES assessment for decision making in urban planning [67], which would allow the feedback loop between ESs and the planning and management of green infrastructures to be closed [68]. The use of ES knowledge to assess alternative scenarios implies specific requirements, such as selecting appropriate indicators for measuring the expected outcomes [72]); the assessment of integrated ES and potential trade-offs [73–75] (e.g., between social and ecological dimensions); and considering the specific needs of various stakeholder groups [76].

Building on above-reported aspects, this paper aims to contribute to filling the existing knowledge gap, and to the mainstreaming of mapping and valuation of ES proceeding from urban NBSs. It specifically aims to address the challenge of integrating multiple ES values in urban decision-making assessments [77,78]. It assesses possible alternative land use and redevelopment scenarios for the management of a selected brownfield, consisting of a former industrial, highly contaminated site in Northeast Italy (see Section 2.1 below), and investigates the potential contribution of urban NBSs in enabling the recovery of the area, while ensuring a flow of ESs generating benefits for local communities. Selected ESs that are expected from the two scenarios are assessed and quantified both in biophysical and monetary terms. Research results can therefore support and inform future decision making about management options regarding the selected case study area, while contributing to advancing knowledge on the use of NBSs as tools for the redevelopment of urban marginal areas.

The paper is organized into five main sections: Section 1 introduces the research topic as well as the objectives and structure of the article; Section 2 provides information about the case study area and the methodological aspects; Section 3 delivers results that are then discussed into Section 4; and finally, Section 5 summarizes the research findings and draws conclusions.

2. Materials and Methods

In this section, the case study area is briefly presented (Section 2.1); then, intervention scenarios (Section 2.2) and methodological approaches for their assessment and evaluation (Section 2.3), as well as the models and data input/output used for them (Section 2.4), are described in detail.

2.1. Case Study Area

Brescia (Eastern Lombardy, Northern Italy) is the second largest city in Lombardy in terms of population (197,307 inhabitants, i.e., 2184.05 inhabitants/km² [79]) after Milan (Figure 1a,b). The city is at the heart of one of the most industrialized areas in Italy, and of a super-specialized district focused on the secondary manufacturing sector; however, like other cities in Europe, Brescia has followed the model of delocalization for its industrial activities and is now undergoing a transition towards becoming a post-industrial city [80]. The case study area is located within the contaminated Site of National Interest (in Italian Sito di Interesse Nazionale, hereinafter, SIN) Brescia-Caffaro, in the South-Western part of the municipality. In more detail, the research focuses on farming areas located in the western part of the SIN and covering 97.4 ha in total, 64.2 ha of which (i.e., about 66%)

actually corresponds to farmlands, and the remaining part being covered by other land uses (Figure 1c). The area, located just a few hundred meters from the historic center of the town, has been home to the chemical industry Caffaro. It has been operating there since 1906, producing caustic soda, and from the 1930s, it produced organic chlorine compounds; from 1938 to 1984, it specialized in polychlorinated biphenyls (PCBs). Streams, underground water, and soil within the area have been heavily contaminated by various compounds such as PCB and heavy metals, including mercury and arsenic [81,82]. Due to growing concerns about impacts on both environmental resources and human health, and due to visibility in the media, the debate about the management of the area and land reclamation solutions has increased in the last few decades. Farming for human food and feed production in the area has been banned from 2002, with only a few exceptions. Additional restrictions on human activities in the area, e.g., the excavation, removal, and disposal of soil, have been introduced by local authorities. The Regional Agency for Agriculture and Forestry Services (in Italian Ente regionale per i servizi all'agricoltura e alle foreste, hereinafter ERSAF) has been considering alternative management and land reclamation solutions, among which are the creation of green areas and a permanent urban forest as alternatives to the use of traditional reclamation technologies, such as thermal treatment technologies. Besides reducing the risks associated to contamination and facilitating the recovery of the area, the development of alternative NBSs is expected to deliver additional benefits in the form of ESs offered to the local population. Two possible intervention scenarios have been developed by ERSAF and are described in Section 2.2 below.



Figure 1. Case study area: (a) Brescia municipality within the national context; (b) SIN Brescia-Caffaro study area within Brescia municipality; and (c) SIN Brescia-Caffaro study area in detail.

2.2. Intervention Scenarios

Two possible future intervention scenarios were identified by ERSAF for the case study area: (i) scenario 1, consisting of an urban forest scenario (Figure 2a), which aims to maximize the forest area with native broadleaves (e.g., *Quercus robur*, *Carpinus betulus*, *Acer campestre* etc.) within the targeted site; and (ii) scenario 2, consisting of a scenario involving meadows with sparse trees (Figure 2b), where native broadleaf species—partly overlapping with those selected for scenario 1—are irregularly planted over permanent and multiple-species grass areas at a low density, corresponding to about a 10 to 20 m distance between neighboring trees. As for the meadows, scenario 2 includes the use of grass species, such as tall fescue (*Festuca arundinacea*) that, in addition to demanding low maintenance have been tested and confirmed to be effective for soil phytoremediation [83–85].

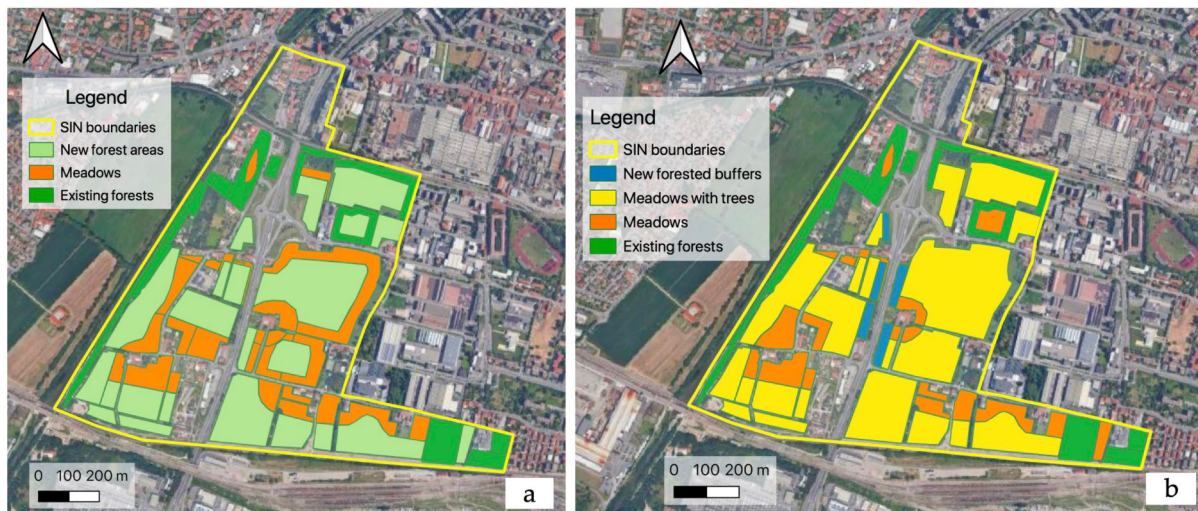


Figure 2. Intervention scenarios and their different land uses: (a) urban forest scenario and (b) meadows with sparse trees scenario.

Table 1 reports details about different land uses and their area for each of the two scenarios.

Table 1. Intervention scenarios and land use categories within them.

Land Use Categories	Urban Forest (Scenario 1)		Meadows with Sparse Trees (Scenario 2)	
	Area (ha)	%	Area (ha)	%
Meadows	15.78	16.2%	8.78	9.0%
Meadows with trees	-	-	35.08	36.0%
Existing forest areas	9.35	9.6%	9.35	9.6%
New forest areas	30.75	31.6%	-	-
New forested buffers	-	-	2.44	2.5%
Agriculture land (not for food or feed production)	8.32	8.5%	8.55	8.8%
Other land uses (developed areas)	32.40	34.1%	33.2	34.1%
Total	97.40	100.0%	97.40	100.0%

For scenario 1, it was assumed that maintenance activities will be implemented for the first three years after planting and will consist of grass cutting and irrigation on demand, to reduce the risk of mortality. Management operations will consist of two thinning rounds: a first round at year 10, removing 25 to 30% of existing trees (warped, shadowed and dominated, etc.) corresponding to an estimated harvested volume of 50–75 m³/ha; and a second round between year 30 and year 40, removing 30 to 50% of existing trees, i.e., an estimated harvested volume of 250–350 m³/ha.

2.3. Methodological Approaches for Ecosystem Service Assessment

For both scenarios, a set of nine ESs was defined in cooperation with ERSAP specialists. The selected ESs cover the three main ES sections according to the Common International Classification of Ecosystem Services (CICES) version 5.1 [86]. Specific assessment approaches were identified for each of them (Table 2). The provision of biomass and fibers for processing and energy (1.1) was assessed only in the case of scenario 1, as no forest management intervention was forecast for scenario 2; meanwhile, phytoremediation capacity (2.1) was assessed only for scenario 2 due to a lack of robust literature regarding phytoremediation capacity for the tree species planned there.

As reported by Table 2, different software suites and models were used for the assessment, including InVEST 3.9.0 [87], i-Tree Eco version 6.0 [88] and ESTIMAP [89]. The selected models were specifically designed to assess most of the ESs addressed by this study, except for the provision of biomass and fibers for processing and energy, and phyto-remediation capacity. Selected software suites also included models that allow for the assessment of carbon sequestration; however, they tend to be data-intensive. In these three cases, alternative methods and approaches were used. Details about data inputs and methodological aspects for each ES assessed and models/approaches adopted, including details about monetary estimations, are provided in Section 2.4 below.

Table 2. Overview of ecosystem services targeted by the research and assessment approaches.

Ecosystem Services	CICES v 5.1 Section and Code(s)	Rationale and Key-Methodological Aspects of the Assessment Approach
1.1 Provision of biomass and fibers for processing and energy (only for scenario 1)	Provisioning, 1.1.5.2 and 1.1.5.3	• Wood removals per final use (processing and energy) according to forecasted management operations (thinning) • Stumpage prices for different assortments
2.1 Phytoremediation capacity (only for scenario 2)	Regulating, 2.1.1.1	• Half- and full-life of pollutants treated with tall fescue (<i>Festuca arundinacea</i>) [90] • Replacement costs for alternative measures (on-site thermal treatment) that would ensure similar remediation performances
2.2 Removal and filtration of air pollutants	Regulating, 2.1.1.2	• Amount of selected air pollutants intercepted and removed by vegetation • Avoided costs for decreased mortality and incidence of pollution-related pathologies • Model: I-tree Eco
2.3 Protection against hydrogeological risks and control of erosion	Regulating, 2.2.1.1	• Runoff retention and erosion prevention • Replacement costs for alternative measures (lamination basin) that would ensure similar protection performances • Model: InVEST Urban Flood Risk Mitigation
2.4 Pollination	Regulating, 2.2.2.1	• Pollinator abundance index and agriculture crop dependency from pollinators • Production function and market value of pollinator-dependent crops • Model: InVEST Pollinator Abundance and Crop Pollination
2.5 Biodiversity and habitat quality	Regulating, 2.2.2.3	• Habitat quality index depending on the level of integrity/degradation of habitats vis-à-vis selected threats • Benefit transfer from previous studies • Model: InVEST Habitat Quality
2.6 Carbon sequestration	Regulating, 2.2.6.1	• Atmospheric carbon stocked in selected pools (above- and below-ground biomass, and soil) • Benchmark market price for carbon

Table 2. Cont.

Ecosystem Services	CICES v 5.1 Section and Code(s)	Rationale and Key-Methodological Aspects of the Assessment Approach
2.7 Temperature regulation and urban cooling	Regulating, 2.2.6.2	- Cooling capacity and heat reduction index by vegetation - Replacement costs for alternative measures (building conditioning systems) that would ensure similar regulation performances - Model: InVEST Urban Cooling
3.1 Recreation	Cultural, 3.1.1.1 and 3.1.1.2	- Estimated number of visitors based on recreation opportunities. - Benefit transfer - Model: adapted ESTIMAP recreation

For land use data, reference was made to the Regional Land use Database for Lombardy [91], integrated with specific land use data for each intervention scenario. Geospatial data were elaborated using QGIS 3.16.

ES were assessed according to the “with and without” principle [92], i.e., as a difference between values accounted under each of the two intervention scenarios and the baseline conditions. Whenever possible, the economic assessment was performed as an initial (i.e., at present time) accumulation of values, taking into consideration two different time horizons, i.e., 60 years and infinite (present value of an infinite annual series). A 3% discount rate was adopted according to the European Commission’s guidelines for investment appraisal [93].

When annual values were not directly provided as a model output, they were computed starting from present values of terminating annual series, and using the inverse formula for the computation of single annuities.

2.4. Models and Approaches Used for the Assessment: Data Inputs and Methodological Details

Within this section a description of each model/approach used for the assessment and evaluation of the selected ESs is provided, together with details about input data and their sources.

2.4.1. Provision of Biomass and Fibers for Processing and Energy

This ES was only estimated for scenario 1 by referring to expected removals from forecasted management operations (thinning and maintenance, see Section 2.2). It is assumed that biomass retrieved from management activities will only consist of assortments suitable for energy use, i.e., chipped wood from the first thinning round and firewood from the second one. Wood prices for firewood and chipped wood were collected from local Chambers of Commerce.

An overview of input and output data for this approach is reported in Table 3.

Table 3. Input and output data for the assessment and evaluation of the provision of biomass and fibers.

Input Data	Description
Removals, R (m ³)	Removal volume from thinning operation in the urban forest scenario (see Section 2.2 within the main text of the paper). For each thinning round, a minimum and a maximum removal volume were considered
Wood density, WD (kg/m ³)	Density of the main wood species expected to be used in the urban forest [94]
Wood price, Wp (EUR/Mg)	Wood price for firewood (average: 40 EUR/Mg) and for chipped wood (average: 30.50 EUR/Mg) based on market analysis via the Chambers of Commerce of Alessandria, Milan and Brescia. Note: 1 Mg corresponds to 1 metric ton
Output data	Description
Wood value, WV (EUR)	Total value of wood assortments retrieved from the urban forest

The economic value of the biomass and fibers provisioning service was computed according to Equation (1):

$$WV = \frac{R_i \cdot WD_j \cdot Wp_k}{1000} \quad (1)$$

where:

WV = wood assortment value, EUR

R = volume of removals per thinning round i, m³

WD = wood density for each of the j wood species considered, kg/m³

Wp = wood price per assortment k (either chipped wood or firewood), EUR/Mg.

WV values were discounted to present time, then converted into single annuities (a) by considering the reverse formula of a terminating annual series covering 60 years. The infinite annual series case was not considered in this case, as only two thinning rounds have been defined.

2.4.2. Phytoremediation Capacity

This ES was only estimated for scenario 2. Reference was made to specific guidelines for reclamation and phytoremediation for the SIN Brescia-Caffaro [90], and to replacement costs for alternative measures (on-site thermal treatment) that would ensure equivalent remediation performances. The economic value of the phytoremediation capacity equals the unit cost for the on-site thermal treatment multiplied by the volume of soil to be treated. Given the high variability of costs associated with alternative measures, three cost options—i.e., minimum (51 EUR/m³), average (122 EUR/m³) and maximum (194 EUR/m³)—were considered [95]. The total volume of soil to be treated corresponds to 438,600 m³, i.e., the whole contaminated area for a 1 m depth.

An overview of input and output data for the assessment and evaluation of phytoremediation capacity is reported in Table 4.

Table 4. Input and output data for the assessment and evaluation of phytoremediation capacity.

Input Data	Description
Time needed to fully remove pollutants treated with <i>Festuca arundinacea</i> (years)	90 years. In 60 years, 80% of the pollutants are removed [90]
Time needed to fully remove pollutants treated with alternative measures (on-site thermal treatment) (years)	0.25 to 0.5 [95]
Volume of soil to be treated	438,600 m ³
Unit cost of alternative measures (on-site thermal treatment) (EUR/m ³)	Minimum: 51 EUR/m ³ , Average: 122 EUR/m ³ , Maximum: 194 EUR/m ³ [95]
Output data	Description
Value of phytoremediation capacity (EUR)	Total value of the phytoremediation capacity corresponding to the cost of the alternative measures

2.4.3. Removal and Filtration of Air Pollutants

i-Tree Eco version 6.0, developed by the United States Department of Agriculture Forest Service [88], was used to assess and evaluate this ES. The pollutants considered included Ozone (O₃), Nitrogen dioxide (NO₂), Carbon monoxide (CO), Sulfur dioxide (SO₂), and fine particles, i.e., particulate matter (PM 2.5).

The economic value of this ES was estimated in terms of avoided costs, with reference to the expected reduction in mortality and illness rates due to the reduced amount of pollutant concentration in the air. The model estimated costs based on the open-source computer program Environmental Benefits Mapping and Analysis Program—Community Edition (BenMAP-CE) [96], with reference to a target population exposed to pollution risks and, therefore, benefiting of any reduction in pollutant concentration. For this aim, the population living within a radius of 1 km around the case study area was considered the

target population. This radius was assumed to be appropriate for a perceivable reduction in pollutant concentration and air quality [97].

Table 5 shows input and output data for the model.

Table 5. Input and output data for the assessment and evaluation of removal and filtration of air pollutants.

Input Data	Description
Tree species and diameter (cm) at year 60	csv file reporting, for each tree, the species name and the diameter at year 60. Diameters were estimated based on [98] for the urban forest scenario and on [99] for the meadows with sparse trees scenario. For species not included within the model, similar species were considered as proxies
Precipitation and pollutant concentration data	The model automatically accessed data from selected weather stations within the targeted area. Data for the Brescia area date back to 2015
Output data	Description
Removed pollutants (kg)	Total pollution removed per year and per pollutant type
Economic value of the removal and filtration of air pollutants (EUR)	Economic value of the removal and filtration of air pollutants based on avoided costs due to the expected reduction in mortality and illness rates

2.4.4. Protection against Hydrogeological Risks and Control of Erosion

This ES was assessed and evaluated using the InVEST 3.9.0 Urban flood risk mitigation model [100], which calculates the runoff depth and runoff depth reduction from rainfall depth, i.e., the amount of runoff retained compared to a given precipitation volume, using the Curve Number method [101,102]. Input data for the model, as well as outputs, are shown in Table 6. The economic value of the ES was assessed via the replacement cost method, using a lamination basin as a surrogate good, assuming a unit cost of 400 EUR/m³, estimated via the Regional Law on 23rd November 2017, n. 7 of Lombardy Region (art. 16), and adjusted based on [103].

Table 6. Input and output data for the assessment and evaluation of protection against hydrogeological risks and control of erosion.

Input Data	Description
Land cover map	Raster of land use/land cover (LULC) for each pixel (resolution 1 m × 1 m), developed from [91]
Biophysical table	csv file reporting Curve number (CN) values for each LULC type and each hydrological group. CN values were derived from [102]
Depth of rainfall (mm)	Three values, i.e., minimum (26.4 mm, return time: 2 years), intermediate (41.80 mm, return time: 10 years), and maximum (55.9 mm, return time: 50 years), identified from [104]
Soils Hydrological Group Raster	250 m spatial resolution raster of categorical hydrological groups from [105]
Output data	Description
Runoff values (mm)	Raster with runoff values
Runoff retention index	Raster with runoff retention values (unitless, relative to precipitation volume)
Runoff retention volume (m ³)	Raster with runoff retention volume values

2.4.5. Pollination

Pollination was assessed and evaluated using the InVEST 3.9.0 Pollinator Abundance: Crop Pollination model [100]. This model focuses on wild and managed pollinators and uses the availability of nest sites and floral resources within bee flight ranges to derive an index of the abundance of bees nesting. It then uses floral resources, pollinator foraging

activity and flight range information to estimate an index of the abundance of pollinators, and finally, calculates a simple index of the contribution of these pollinators to agricultural production, based on their abundance and crop dependence on pollination. Based on yields per single crop type, it is therefore possible to calculate the crop yield attributable to pollinators and, using crop market prices, estimate the economic value of the pollination ES. Selected pollinator species included bumblebee, bee (miner and carpenter bee), hoverfly, ant, butterfly and wasp. Crop yields for different crop types were retrieved from the Benchmark Yield Database of the National Agriculture Information System [106], while crop prices were collected from the Chambers of Commerce of Milan and Brescia.

Input and output data for this model are reported in Table 7.

Table 7. Input and output data for the assessment of pollination.

Input Data	Description
Land cover map	Raster of land use/land cover (LULC) for each pixel (resolution 1 m × 1 m), developed from [91]. A 5 km buffer around the case study area was considered
Biophysical table	csv file reporting, for each LULC type: (i) nesting availability index, range: (0–1), i.e., a relative index of the availability of the given nesting type within each LULC type; (ii) floral resources index, range: (0–1), i.e., a relative index of the floral abundance (or coverage) as well as the duration of flowering during each season. Spring and Summer were indicated as flowering seasons
Guild table	csv file reporting on each species of pollinator to be modeled. For each species the following information was provided: (i) nesting substrate, range: (0–1); (ii) foraging activity per season, range: (0–1); (iii) average distance each species travels to forage on flowers; and (iv) relative abundance of the species, range: (0–1)
Farm vector	Vector of farm areas indicating crop types and their seasonality, as well as the dependency from both wild and managed pollinators [107,108]. As for the latter, reference was made to a database of bee-hiving activities within Brescia Province, provided by ERSAP
Output data	Description
Farm results	Farm vector enriched with data on average pollinator abundance on the farm for the active season, total yield index (including all types of pollinators, as well as yield independent from pollinators), index of the potential pollination dependent yield attributable to wild pollinators, and index of the total yield attributable to wild pollinators

2.4.6. Biodiversity and Habitat Quality

This ES was assessed and evaluated via the InVEST 3.9.0 Habitat Quality Model [100], which estimates patterns in biodiversity by analyzing land use/land cover in conjunction with threats to species' habitats. The model uses habitat quality as a proxy for biodiversity. It computes a habitat quality index (ranging between 0 and 1) as a function of four factors: each threat's relative impact; the relative sensitivity of each habitat type to each threat; the distance between habitats and sources of threats; and the degree to which the land is legally protected [100]. For the economic evaluation, reference was made to values estimated by [109] regarding the economic loss associated with biodiversity decline due to soil consumption and urban development. Average unit values (EUR/m²) for different land use conversions/transformations were estimated, then linked to different land uses and, finally, multiplied by the corresponding habitat quality index through the raster calculator function in QGIS 3.16.

Detailed information about input and output data for this model is available in Table 8.

Table 8. Input and output data for the assessment and evaluation of biodiversity and habitat quality.

Input Data	Description
Land cover map	Raster of land use/land cover (LULC) for each pixel (resolution 1 m × 1 m), developed from [91]
Threats data	csv file reporting information on each threat's relative importance and the maximum distance over which each threat affects habitat quality. For all threats, impacts were assumed to decay according to a linear decay function. A total of 24 threats were identified (each of them corresponding to a specific land use type, e.g., residential continuous medium-dense urban fabrics, industrial areas or railways etc.), building on [110]. A raster file was developed for, and named after, each threat.
Sensitivity of land cover types to each threat	csv file reporting, for each LULC type, whether or not they are considered habitat (either 1 or 0), and, for LULC types that are habitat, their specific sensitivity to each threat; these are according to a (0–1) range and based on the Biological Territorial Capacity Index [111], and in coherence with [110]
Accessibility	Vector of areas subject to environmental restrictions and protection, as in the Ecological Regional Network (Regional Territorial Plan)
Half-saturation constant	0.5. Default value set by the InVEST model
Output data	Description
Habitat quality	Raster file reporting the habitat quality index; this shows the relative level of habitat quality, ranging between 0 and 1, where values closer to 1 indicate better habitat quality vis-à-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat are given a quality score of 0

2.4.7. Carbon Sequestration

Although selected models allow for the assessment of carbon sequestration, they tend to be data-intensive; therefore, an alternative approach based on the International Panel on Climate Change (IPCC) guidelines [112] and additional stock data from the literature [103,113] was used. For the estimation of the economic value of the ES, the estimated Carbon stock under each scenario was multiplied by an average carbon price, retrieved from existing literature on forest-based carbon-projects and initiatives in Italy [114].

Table 9 includes input and output data for the carbon sequestration model.

Table 9. Input and output data for the assessment and evaluation of carbon sequestration.

Input Data	Description
Land cover map	Raster of land use/land cover (LULC) for each pixel (resolution 1 m × 1 m), developed from [91]
Carbon stock (Mg CO ₂ /ha)	Urban forest: 335.80 MgCO ₂ /ha [113] Meadows with sparse trees: 68 Mg Corg/ha for the meadows [103]. For the tree-component, the total aboveground biomass increment was calculated based on [99]. For species not included within the model, similar species were considered as proxies. The total aboveground biomass was further elaborated to calculate carbon in branches and the belowground biomass pool, via BCEF (Biomass Conversion and Expansion Factor); ratio of below-ground to above-ground biomass and carbon fraction [112]; and finally, C to CO ₂ conversion factor (assuming 1 Mg of carbon equals 44/12 or 3.67 Mg CO ₂)
Annual carbon increment (Mg CO ₂ /ha)	Urban forest: 7.5328 Mg CO ₂ /ha [113]
Carbon price (EUR/Mg CO ₂ eq)	10.68 [114]
Output data	Description
Carbon stock (Mg CO ₂ eq)	Stock of carbon under the two scenarios at year 60th, converted into Mg CO ₂ eq
Economic value of the carbon sequestration (EUR)	Total economic value of the carbon sequestration ES

2.4.8. Temperature Regulation and Urban Cooling

This ES was assessed and evaluated via the InVEST 3.9.0 Urban Cooling Model [100] that—based on shade, evapotranspiration, and albedo, as well as distance from cooling islands (green areas larger than 2 ha)—calculates a heat mitigation index, estimating a temperature reduction by vegetation and green spaces. The model also estimates the economic value of the ES in terms of avoided costs associated with avoided energy consumption due to the cooling effects of vegetation.

Input and output data for the temperature regulation and urban cooling model are summarized in Table 10.

Table 10. Input and output data for the assessment of temperature regulation and urban cooling.

Input Data	Description
Land cover map	Raster of land use/land cover (LULC) for each pixel (resolution 1 m × 1 m), developed from [91]
Biophysical table	csv file reporting, for each LULC type: (i) shade, range: (0–1); (ii) crop coefficient [115]; (iii) albedo [116]; (iv) green area (either 0 or 1); (v) building intensity, range: (0–1)
Reference evapotranspiration (mm)	Raster of reference evapotranspiration according to the FAO Penman–Monteith methodology [115]
Area of interest	Vector of the boundaries of the case study area
Green area maximum cooling distance (m)	Distance over which large urban areas (>2 ha) within the case study area have a cooling effect. Defined as 200 m based on [117]
Baseline air temperature (°C)	23.4 °C [118]
Magnitude of the urban heat island (UHI) effect	3.5 °C [119]
Air temperature maximum blending distance (m)	2000 m. Default value set by the InVEST model.
Building footprints	Vector with built infrastructure footprints, developed based on the Brescia Municipal Technical Map (<i>Carta Tecnica Comunale</i> , version 20th March 2021), using the reference vector “Edificio” (i.e., building).
Energy consumption table	csv file reporting energy cost per type of building—residential (0.15 EUR/Kwh), industrial (0.12 EUR/Kwh) and other (0.10 EUR/Kwh)—derived as average values from online data by the Italian Regulatory Authority for Energy, Networks and Environment (<i>Autorità di Regolazione per Energia Reti e Ambiente</i> , ARERA).0.54% increase in the daily electricity load for each degree of temperature increase [120]
Average relative humidity	72% [118]
Weights of factors	Shade: 0.6, Albedo: 0.2, Evapotranspiration: 0.2. Default values set by the InVEST model.
Output data	Description
Heat mitigation index	Raster with heat mitigation (hm) index values (unitless) showing the cooling effect for the baseline and under each intervention scenario
Energy savings (kWh)	Avoided energy consumption due to the cooling effects for the baseline and under each intervention scenario
Energy savings (EUR)	Avoided costs associated with avoided energy consumption, due to the cooling effects, for the baseline and under each intervention scenario

Based on model outputs, the Discomfort Index (DI) was calculated. This corresponds to a physiological thermal stress indicator for people, based on dry-bulb and wet-bulb temperature [121,122] according to the following:

$$DI = 0.4 (Ta + Tw) + 4.8 \quad (2)$$

where:

Ta = dry-bulb temperature (°C) from the InVEST Urban Cooling model

Tw = wet-bulb temperature (°C) from the InVEST Urban Cooling model.

2.4.9. Recreation

Recreation was assessed based on an adapted version of ESTIMAP [89,123] a GIS-based model for the assessment, estimation, and mapping of ESs developed by the Joint Research Centre (JRC) of the European Commission. The model computes the Recreational Opportunity Spectrum (ROS), ranging between 0 and 1, which indicates the degree of recreation provision based on a combination of multiple natural, accessibility, and use-related features (Figure 3).

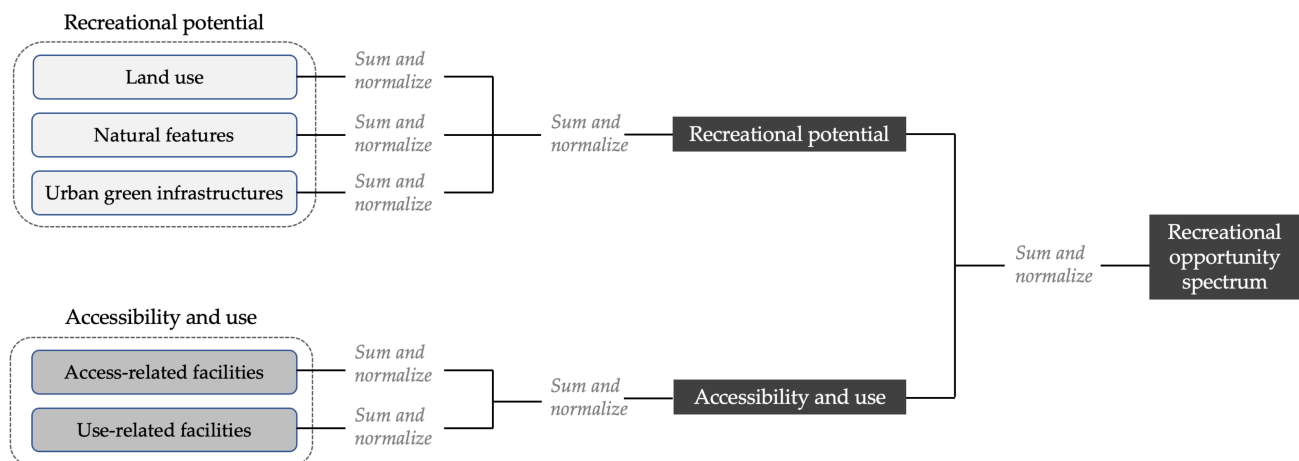


Figure 3. Flow-chart of methodological steps for the assessment of recreation. Adapted from [89,123].

Table 11 reports input and output data for the recreation model.

Table 11. Input and output data for the assessment and evaluation of recreation.

Input Data	Description
Land cover map	Raster of land use/land cover (LULC) for each pixel (resolution 1 m × 1 m), developed from [91]
Recreation potential	Scores for natural features and urban green infrastructures adapted from [123]. For the identification of natural features, reference was made to ecological features as in the Lombardy Regional Technical Map (<i>Carta Tecnica Regionale</i>)
Accessibility	Score for areas varying according to their distance from pedestrian and bicycle paths. Paths were identified based on the Lombardy Regional Technical Map. Scores were adapted from [123]
Use-related facilities	Score for areas including use-related facilities (e.g., playgrounds, dog areas). Facilities and infrastructures were identified based on the Lombardy Regional Technical Map. Scores were adapted from [123]
Output data	Description
Recreational opportunity spectrum (ROS)	Raster with ROS values (unitless, (0–1))

For the economic evaluation, the spatial distribution of potential users and the number of trips to the area were estimated through distance-decay modelling, assuming that the recreation potential decreases as the distance from a specific feature (e.g., forest area) increases [89]. The following distance decay function was adopted [89,124,125]:

$$f(d) = \frac{1 + K}{K + e^{\alpha \cdot d}} \cdot \text{ROS} \quad (3)$$

where:

d = distance in meters from the specific feature

α and K = e size and shape parameters of the function adjusted according to a distance threshold. They were assumed to be 0.0009 and 30, respectively, corresponding to distance thresholds of 4000 m at which the score was decreased by 50%, and 8000 at which the score was zero [89]. The choice of parameter values also reflects limitations in access to the area, for instance, by making only specific paths and tracks viable, due to contamination risks.

The number of trips was attributed to the resident population [126] to calculate the outdoor recreation demand, assuming that all inhabitants in the case study area had similar desires in terms of (everyday life) outdoor recreational opportunities, but their level of fulfillment depended on proximity to recreation sites [89,125]. The population living within an 8000 m radius was considered, making reference to 300 m distance breaks [125,127]. The economic value associated to each trip was 1.44 EUR/trip, derived from previous studies within similar urban contexts [103] and adjusted via the ROS.

3. Results

This section provides the research results, distinguishing them into the assessment of single ESs (Section 3.1), and a summary of results and total value for the two intervention scenarios (Section 3.2).

3.1. Assessment of Single Ecosystem Services

3.1.1. Provision of Biomass and Fibers for Processing and Energy

For the first thinning round (year 10), removals are expected to range between 50 and 70 m³/ha, over a total area covering 30.75 ha: this corresponds, in total, to 1150.93–1611.30 Mg of chipped wood. By considering a unit price of 30.50 EUR/Mg, a total economic value between EUR 35,103.32 and 49,144.65 is estimated. When discounted to the present time, this equals EUR 26,120.17 to 36,568.24. For the second thinning round (year 35), the removed volumes range between 250 and 350 m³/ha, i.e., between 5764.64 and 8056.50 Mg of firewood in total. Assuming a unit price of 40 EUR/Mg, this corresponds to EUR 230,185.71–322,260, equivalent to discounted values ranging between EUR 81,804.18 and 114,525.85. In total, the present value expected from the two rounds of thinning falls within EUR 107,924.35 and 151,094.09, i.e., an estimated annual value between EUR 3899.63 and 5459.48.

3.1.2. Phytoremediation Capacity

It is estimated that tall fescue can remove all pollutants in 90 years, while in 60 years, 80% of the pollutants are removed [90]. Based on the three different unit cost hypotheses for alternative measures (on-site thermal treatment)—i.e., minimum, average and maximum unit cost—the estimated annual ES values range between EUR 109,749 and 417,475, with an intermediate value of EUR 262,536, and corresponding present values (over 60 years) ranging from EUR 3 million to EUR 11.5 million, with an intermediate value of about EUR 7.3 million.

3.1.3. Removal and Filtration of Air Pollutants

The two intervention scenarios show similar profiles; however biophysical and economic values for scenario 1 are about four times higher (Figure 4): the forest is estimated to remove some 2.91 Mg/year of pollutants, while for meadows with sparse trees, the estimation is approximately 0.67 Mg/year. Under both scenarios, the pollutants removed mainly consist of Ozone (O₃) (61%), and Nitrogen dioxide (NO₂) (31%), with lower contributions by Carbon monoxide (CO) (about 4%) and Sulfur dioxide (SO₂) (3.5%), and a marginal contribution by fine particles, i.e., particulate matter (PM) 2.5 (0.5%). However, as for the economic value, while O₃ still ranks first, PM2.5 follows, because it is the most health-harmful among the pollutants considered by iTree. The economic value of this ES is estimated to be 9086.84 EUR/year in the case of the urban forest and 2209.72 EUR/year in

the case of meadows with sparse trees. This corresponds, respectively, to a present value of EUR 48,589.32 and EUR 11,213.33 over a 60-year-long time horizon, or EUR 100,000.57 and EUR 23,715.42 over an infinite time horizon.

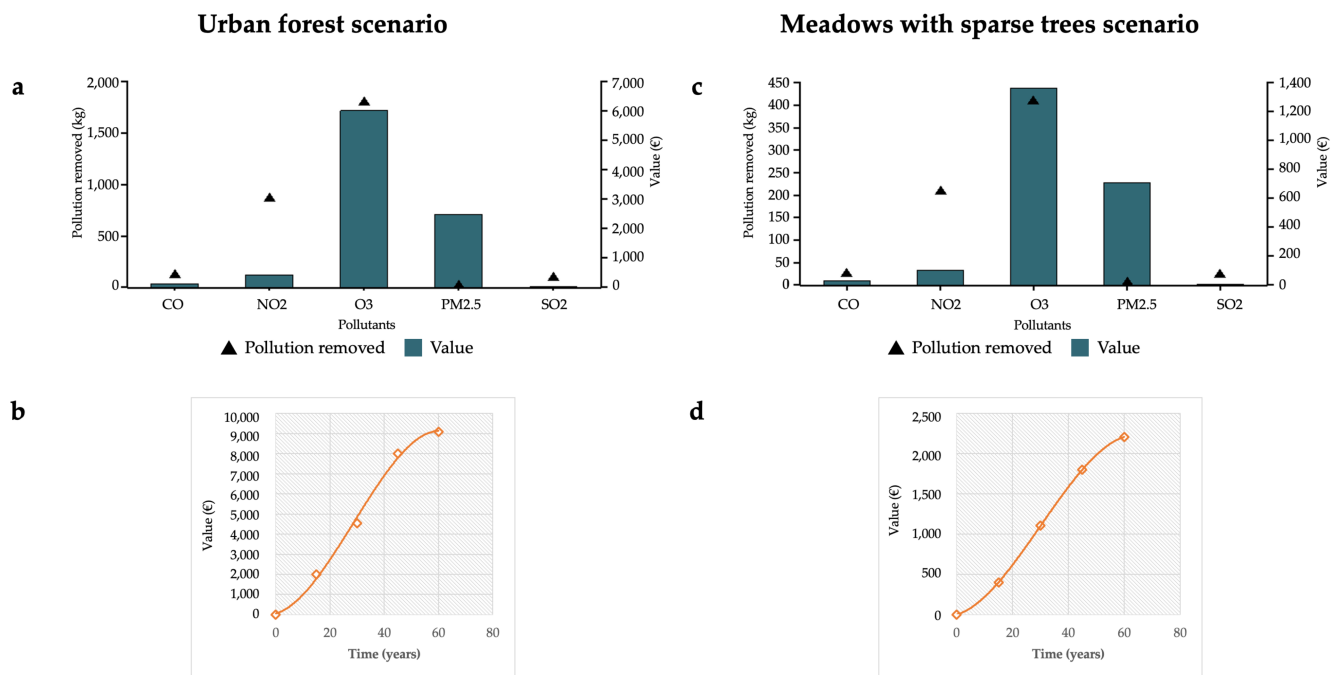


Figure 4. Total pollution removed and economic value of the ES per year and per pollutant (a,c), and total value variation over time (b,d) under the two intervention scenarios. Please note that the charts use different scales on the vertical axes.

3.1.4. Protection against Hydrogeological Risks and Control of Erosion

The runoff retention results are higher for scenario 1 than for scenario 2 under all the rainfall depth values (h) and return time conditions considered (Figure 5). For scenario 1, the runoff retention ranges between 20,949 m³ (equivalent to 0.021 m³/m²)—for an h value of 26.4 mm—and 34,400 m³—for an h value of 55.9 mm (0.035 m³/m²), with an intermediate volume of 28,877 (0.030 m³/m²) for an h value of 41.8 mm. For scenario 2 the runoff retention varies between 20,289 m³ (0.021 m³/m²) for h equal to 26.4 mm and 32,250 m³ (0.033 m³/m²) for h equal to 55.9 mm, with an intermediate value of 27,454 m³ (0.028 m³/m²) for h equal to 41.8 mm.

The modelled biophysical values reflect economic ones: annual values estimated for this ES range between 40,423 and 111,432 EUR/year for scenario 1 (intermediate value: 80,061 EUR/year), and between 30,882 and 81,789 EUR/year for scenario 2 (intermediate value: 59,488 EUR/year). For scenario 1, the present values fall within EUR 1.12 and 3.08 million (over a 60-year-long time horizon) and EUR 1.35 and 3.71 million (infinite time horizon). For scenario 2, they range between EUR 0.85 and 2.26 million (over a 60-year-long time horizon) and between EUR 1.03 and 2.73 million (over an infinite time horizon).

3.1.5. Pollination

Both intervention scenarios result in improved habitat for pollinators and, therefore, in better conditions for their abundance and activities; these ultimately have effects on the economic value of the ES in terms of the production of pollinator-dependent crops. This corresponds to annual values estimated to be 6200.56 EUR/year for scenario 1 and 5436.50 EUR/year for scenario 2. The present value for 60 of these annuities corresponds to EUR 171,603.92 and EUR 150,458.16, respectively, while the present value when considering an infinite time horizon corresponds to EUR 206,685.25 and EUR 181,216.62, respectively.

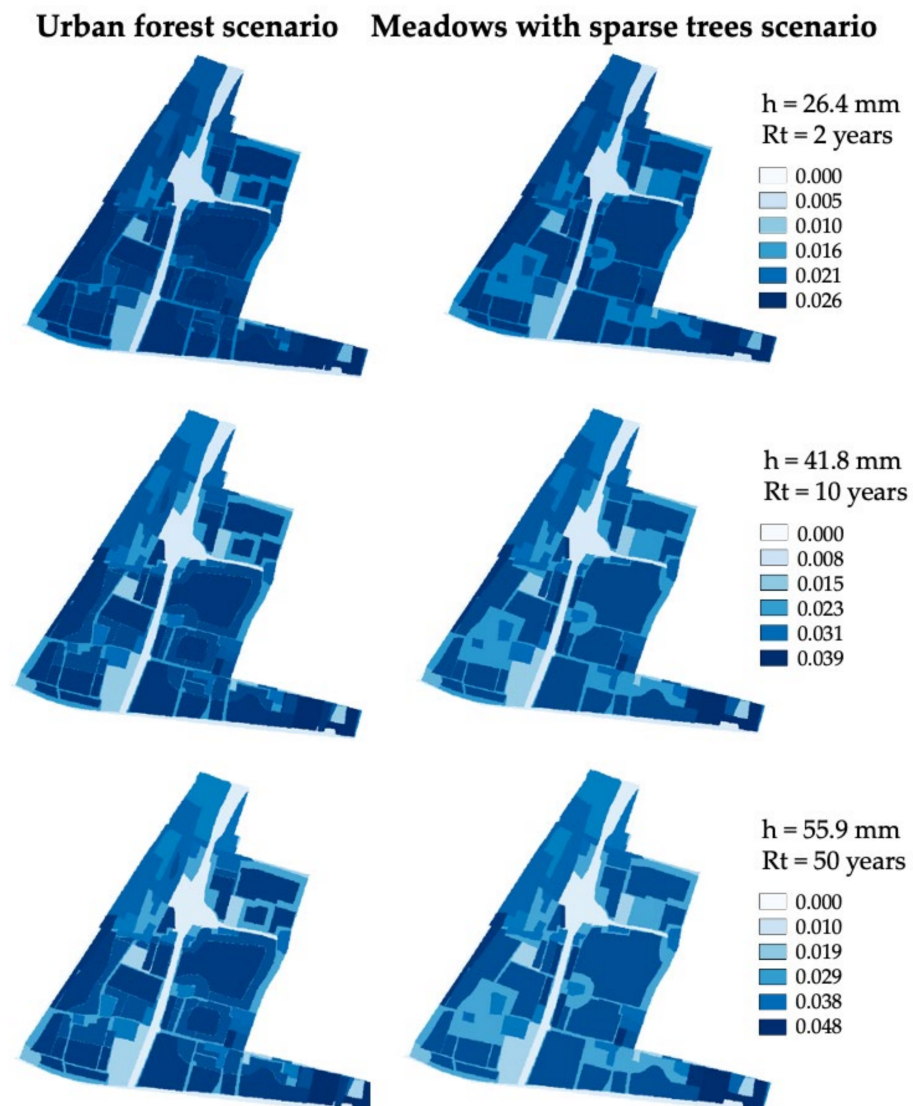


Figure 5. Runoff retention (m^3) for the baseline and the two intervention scenarios under different depth of rainfall (h , mm) and return time conditions (R_t , years).

3.1.6. Biodiversity and Habitat Quality

The habitat quality index varies greatly under both scenarios (Figure 6), showing the highest values for land use categories such as riparian woods, broadleaf high forests, and permanent meadows with and without trees and shrubs. The average value of the index is highly influenced by the relative abundance of the most valuable land uses and habitats, with scenario 1 showing a higher value than scenario 2 (0.609 vs. 0.549). This reflects the economic values; the annual value for the urban forest corresponds to EUR 12,024.87 and for the meadows with sparse trees, 5836.46 EUR. The accumulation, up to the present time, of 60 of these annuities is equal to EUR 0.41 million and EUR 0.24 million, respectively. The present value, when considering an infinite time, is equal to EUR 0.49 million and EUR 0.29 million.



Figure 6. Habitat quality index for the two intervention scenarios.

3.1.7. Carbon Sequestration

Scenario 1 shows better performances in terms of carbon sequestration, with an estimated stock of 11,724.63 MgCO₂ (91% due to the forest stand and the rest to the meadows), i.e., more than 1.8 times the stock estimated for scenario 2 (6376.72 MgCO₂). As for the latter, the main pools are soil (about 47%) and standing trees (40%). In the case of soil, reference was made to the stock at the 60th year rather than considering an annual increment. Assuming a unit price of 10.68 EUR/Mg of CO₂eq [114], an annual value of EUR 2473.85 was estimated for scenario 1 and EUR 471.62 for scenario 2. This corresponds, respectively, to present values of EUR 19,309.04 and EUR 6152.90 (over a 60-year-long time horizon), and EUR 82,461.56 and EUR 15,720.59 (over an infinite time horizon).

3.1.8. Temperature Regulation and Urban Cooling

The heat mitigation index shows a decreasing trend when moving from the core of the case study area to more marginal areas, particularly when moving northeast (Figure 7). The index varies within similar ranges (0.020–0.837) for the two intervention scenarios; however, the average value is higher for scenario 1 (0.404) than for scenario 2 (0.394). This reflects the expected average air temperature within buildings in the area: 24.45 °C for scenario 1 and 25.49 °C for scenario 2. The dry- and wet-bulb temperatures estimated by the model were used for the calculation of the Discomfort Index [121,122]; in both cases, it is below 24 °C (23.86 °C for scenario 1 and 23.89 °C for scenario 2) which, according to [121], means that less than 50% of the population in the area feels discomfort. Notably the same index computed for the baseline situation is 26.06 °C, implying that more than 50% of the population feels discomfort [121].

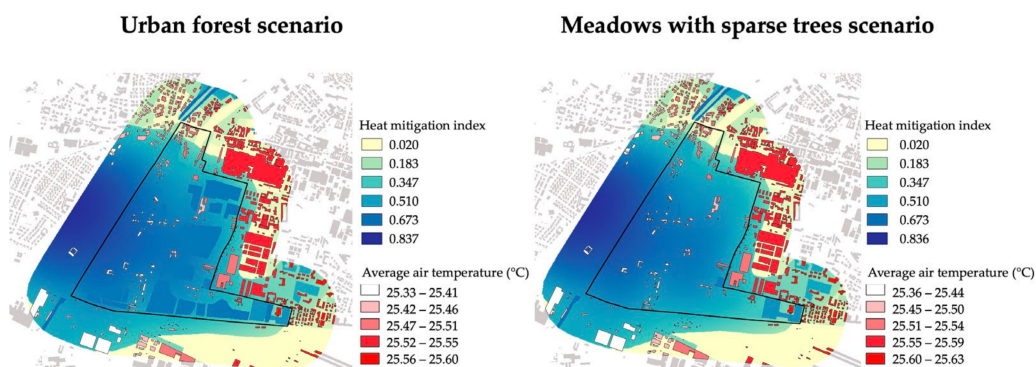


Figure 7. Heat mitigation index and average air temperature (°C) for the two intervention scenarios.

The cooling effect of the urban forest is estimated to save 219.04 EUR/day in terms of energy savings for the buildings within a 200 m-wide buffer around the case study area.

Assuming that there are 73.5 summer days/year [128], this corresponds to 16,099 EUR/year. The present value, when considering 60 annuities, would correspond to EUR 445,561, while the present value, over an infinite time horizon, would be EUR 536,648. In the case of the meadows with sparse trees, the estimated daily savings are 213.17 EUR/day, corresponding to 15,668 EUR/year. The initial accumulation over sixty years would lead to a total value of EUR 433,621, while the present value over an infinite time would be EUR 522,267.

3.1.9. Recreation

The Recreational Opportunity Spectrum (ROS) varies across the site and depending on the scenario. It shows an average value that is higher for scenario 1 (0.371) than for scenario 2 (0.351) (Figure 8). When focusing just on the areas subject to land use change under the two scenarios:

- In scenario 1, new forest areas show a ROS ranging between 0.415 and 0.7, with an average value of 0.608, while meadows associated with them have a ROS ranging between 0.213 and 0.674, with an average score of 0.42.
- In scenario 2, the new meadows show a ROS ranging between 0.213 and 0.622, with an average value of 0.419.

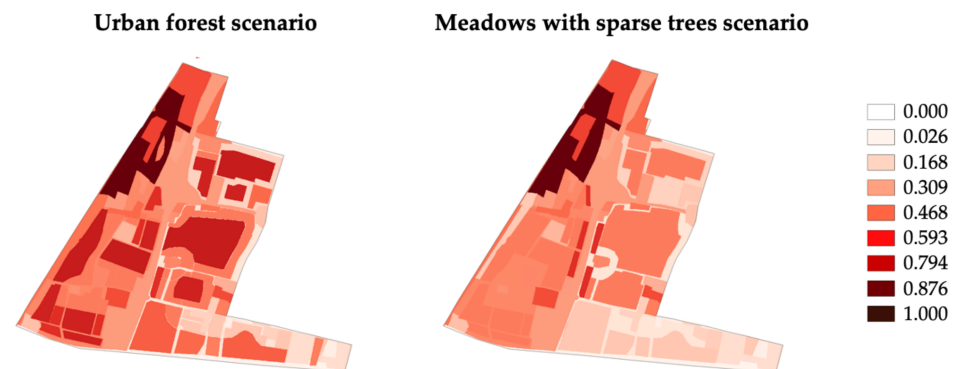


Figure 8. Recreation Opportunities Spectrum for the two intervention scenarios.

The expected number of visits per year is 59,251 for scenario 1 and 56,316 for scenario 2; this corresponds to annual economic values of, EUR 31,654 and EUR 28,464, respectively (i.e., about 8555 EUR/year and 5365 EUR/year higher than the values estimated for the baseline). The present value of these annuities over 60 years corresponds to EUR 236,764.45 and EUR 148,479.40, respectively, while the initial accumulation in the case of an infinite time is EUR 178,883.33 and EUR 948,808.72.

3.2. Summary of Results and Total Value for the Intervention Scenarios

A summary of the estimated values for all ESs considered within this research is provided in Table 12 for scenario 1, and in Table 13 for scenario 2. The relative sharing of ES values under the two scenarios is reported in Figure 9.

Both intervention scenarios show ES values that exceed the baseline, thus indicating substantial improvements associated with NBS development. When considering a single ES, scenario 1 systematically performs better than scenario 2, with the only exception being the phytoremediation capacity, which is not considered in the case of the urban forest. When considering the total value for the full set of ESs taken into account, scenario 2 shows the highest value, mainly due to the contribution of the phytoremediation capacity. The total annual flow values estimated are 139,181 EUR/year for scenario 1 and 357,011 EUR/year for scenario 2, equivalent to 0.42 EUR/year m^2 and 0.82 EUR/year m^2 , respectively, and to 0.70 EUR/year and 1.79 EUR/year per single inhabitant living within Brescia municipality. When considering the ES stocks instead of their annual flows, the estimated economic value for the stock over a 60-year period is EUR 3.60 million for scenario 1 (10.81 EUR/ m^2) and EUR 9.83 million for scenario 2 (22.05 EUR/ m^2). When an infinite time horizon is considered, the total present value of the stock amounts to EUR 4.28 million for scenario 1

(12.84 EUR/m²) and EUR 3.10 million for scenario 2 (6.85 EUR/m²). As for the latter, the values are influenced by the fact that the stock value for the phytoremediation capacity ES is not considered under an infinite time horizon, as the remediation action would terminate in 90 years.

Note: scenario 1 does not include phytoremediation capacity, and scenario 2 does not include the provision of biomass and fibers for processing and energy. In scenario 2 phytoremediation is not accounted for in the case of infinite time.

Table 12. Summary of ES values for scenario 1—urban forest.

Ecosystem Services	Annual Value		Present Value (60 Years)		Present Value (Infinite Time)	
	Total (EUR/y)	Unit (EUR/y m ²)	Total (EUR/y)	Unit (EUR/y m ²)	Total (EUR/y)	Unit (EUR/y m ²)
1.1 Provision of biomass and fibers for processing and energy	4679.56	0.015	129,509.22	0.42	-	-
2.1 Phytoremediation capacity	-	-	-	-	-	-
2.2 Removal and filtration of air pollutants	9086.84	0.02	48,589.32	0.13	100,000.57	0.27
2.3 Protection against hydrogeological risks and control of erosion	80,060.95	0.27	2,215,732.00	7.38	2,668,698.43	8.89
2.4 Pollination	6200.56	0.01	171,603.92	0.37	206,685.25	0.44
2.5 Biodiversity and habitat quality	12,024.87	0.04	332,795.09	1.08	400,829.04	1.30
2.6 Carbon sequestration	2473.85	0.01	21,254.20	0.05	82,461.56	0.27
2.7 Temperature regulation and urban cooling	16,099.44	0.02	445,561.00	0.61	536,648.00	0.74
3.1 Recreation	8555.00	0.03	236,764.45	0.77	285,166.67	0.93
Total	139,181.06	0.42	3,601,809.20	10.81	4,280,489.52	12.84

Table 13. Summary of ES values for scenario 2—meadows with sparse trees.

Ecosystem Services	Annual Value		Present Value (60 Years)		Present Value (Infinite Time)	
	Total (EUR/y)	Unit (EUR/y m ²)	Total (EUR/y)	Unit (EUR/y m ²)	Total (EUR/y)	Unit (EUR/y m ²)
1.1 Provision of biomass and fibers for processing and energy	-	-	-	-	-	-
2.1 Phytoremediation capacity	262,535.77	0.60	7,265,825.49	16.57	-	-
2.2 Removal and filtration of air pollutants	2209.72	0.03	11,213.33	0.14	23,715.42	0.31
2.3 Protection against hydrogeological risks and control of erosion	59,488.15	0.13	1,646,368.00	3.56	1,982,938.23	4.28
2.4 Pollination	5436.50	0.01	150,458.16	0.32	181,216.62	0.39
2.5 Biodiversity and habitat quality	5836.46	0.02	161,527.45	0.43	194,548.82	0.63
2.6 Carbon sequestration	471.62	0.001	11,559.39	0.03	15,720.59	0.04
2.7 Temperature regulation and urban cooling	15,668.00	0.02	433,621.00	0.60	522,267.00	0.72
3.1 Recreation	5365.00	0.01	148,479.40	0.40	178,883.33	0.48
Total	357,011.22	0.82	9,829,052.22	22.05	3,099,290.00	6.85

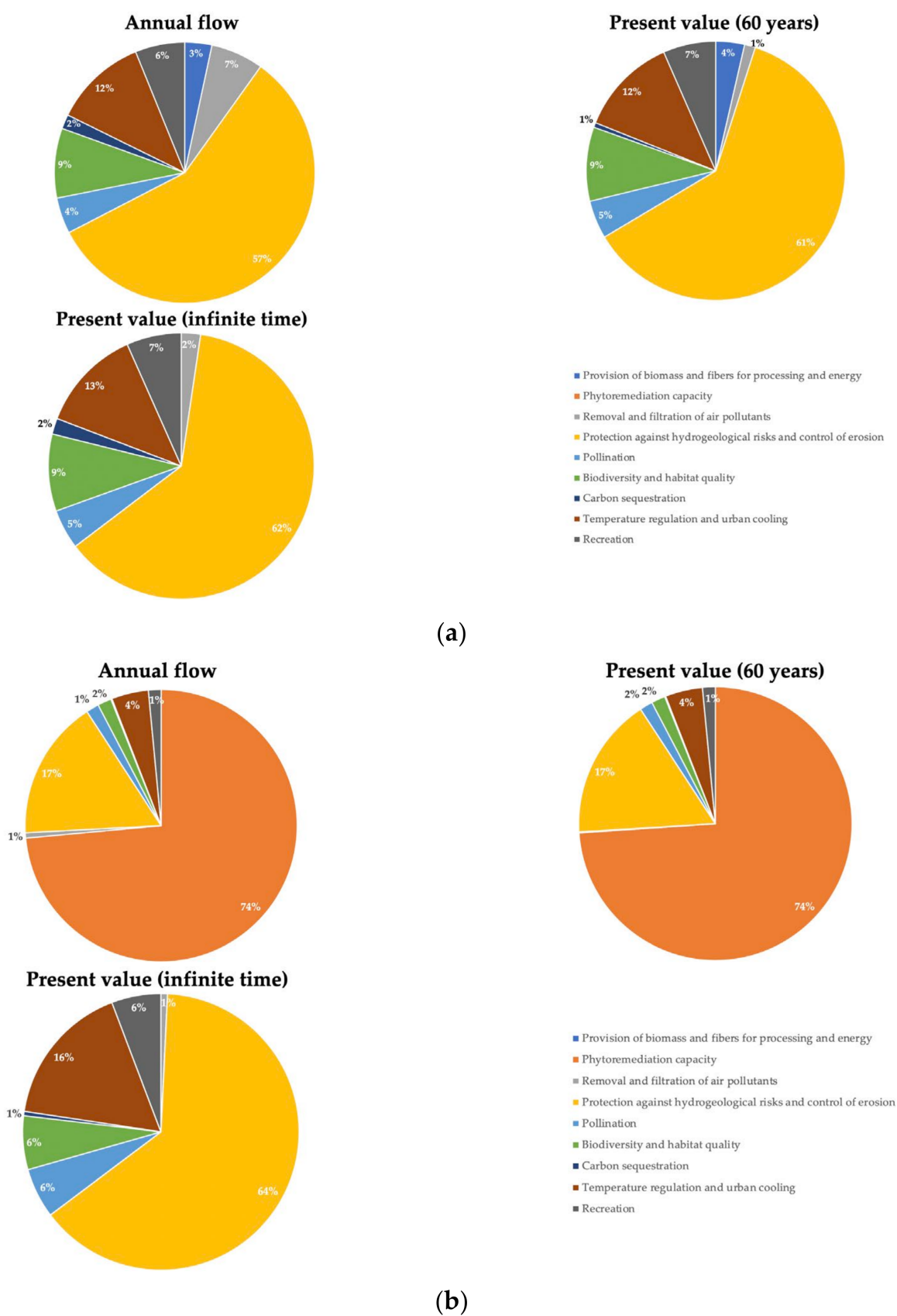


Figure 9. Relative sharing of ES values in terms of annual flow, present value over 60 years and an infinite time horizon for the two intervention scenarios. (a) Scenario 1—Urban forest, (b) Scenario 2—Meadows with sparse trees.

Under both scenarios, a single ES dominates the total value, with remaining ESs contributing to different extents (Figure 9):

- For scenario 1, more than half of the value (57–62%) is attached to the protection against hydrogeological risks and control of erosion, followed by temperature regulation and urban cooling (12–13%); biodiversity and habitat quality (9%); recreation (6–7%); and pollination (4–5%). Altogether these ESs account, on average, for more than 93% of the total value estimated for the urban forest scenario, while other ESs contribute marginally.
- For scenario 2, phytoremediation capacity is the leading ES (74%), followed by the protection against hydrogeological risks and control of erosion (17%); temperature regulation and urban cooling (4%); pollination; biodiversity and habitat quality; and recreation (2–6% each). When an infinite time horizon is considered, the contribution of phytoremediation capacity is not accounted for; the protection against hydrogeological risks and control of erosion becomes the main ES (64%), and temperature regulation and urban cooling grows up to a 17% contribution.

4. Discussion

Research results show that both brownfield redevelopment scenarios are expected to create urban green spaces, generating a wide range of ESs to an extent that goes far beyond the level of ESs provided under the current conditions. This confirms existing literature on this topic [129], according to which NBSs have the potential to supply multiple ESs and offer opportunities that are beneficial to a vast range of people [67,68]. In particular, urban NBSs often provide local public goods [130], primarily benefitting citizens in the area in which they are located [64].

Regulating ESs contribute the most to the overall estimated ES value; this is, on the one hand, consistent with findings in the literature [15,131], and on the other, very much dependent on the selected set of ESs. The marginal role of provisioning ESs depends on the rationale and general logic behind the two intervention scenarios that, being designed from a public perspective, are not aimed at commodity production; rather, they are aimed at the delivery of benefits to society at large. Moreover, provisioning and, to a lower extent, cultural ESs are subject to the restrictions imposed on current limitations in terms of use of, and access to, the area. All in all, this favors indirect-use values embodied within regulating ESs.

Two regulating ESs largely prevail in terms of value under the two scenarios: phytoremediation capacity, and protection against hydrogeological risks and control of erosion. The latter is functionally linked to the former, as it can be assumed that by improving runoff retention capacity, the transport of polluted soil and sediments towards downstream areas and water bodies, including groundwater, can be reduced [132]. It should not be forgotten that due to the lack of systematic data on phytoremediation projects using trees in urban areas, the phytoremediation capacity was not assessed for scenario 1. However, existing literature indicates that several tree species, including some of those planned to be planted in the new urban forest (e.g., *Quercus robur*, *Carpinus betulus* etc.), have phytoremediation potential and the capacity to withstand stress by pollutants and heavy metals [133]. The total value of ESs delivered under scenario 1 is, therefore, likely to be underestimated, and the gap among the two scenarios is probably narrower. The fact that phytoremediation capacity and protection against hydrogeological risks and control of erosion largely prevail in terms of estimated value does not mean that other ESs delivered by the two scenarios are negligible. This is particularly evident for scenario 1, wherein, besides protection against hydrogeological risks and control of erosion, another six ES make about 40% of the total estimated value.

Further underestimation of ESs is also due to the fact that this study does not consider the full range of potential ESs that could be delivered by the two intervention scenarios; rather, it focuses on a set of ESs selected a priori. While the selected set includes the most plausible ESs given the expected transformation projects, they still exclude some ESs

(e.g., landscape and aesthetics, and other cultural services, such as those falling within the domain of green care initiatives [134] for physical and psycho-social wellbeing) that could bring in additional value. In addition to this, the study does not aim to grasp the total economic value (TEV) of the two intervention scenarios, and some TEV components—in particular, those associated to non-use values—are, therefore, not considered and accounted for.

Notwithstanding the many barriers and challenges, brownfield redevelopment is of relevance due to the processes of de-industrialization and suburbanization, as well as population resettlement occurring within and around urban areas [135]. Within existing settlements, particularly dense ones, there may be limited room for developing additional green spaces; therefore, brownfields could provide opportunities for this [21]. Redeveloped brownfields and green urban brownfields can become vital components of a city's green infrastructure, being connected with, and complementing a wide variety of green features within urban settlements, as well as supporting the connection of urban and rural areas [136]. If properly planned as a mix of developed and green areas, they may be part of an effective strategy to tackle or mitigate land consumption and urban sprawl processes, while at the same time improving quality of urban areas. Ideally, brownfields give opportunities to exploit large sources of land within established communities, often offering already excellent infrastructure [137]. Nevertheless, investors still prefer new locations when investing in development projects, targeting undeveloped land (“green-fields”) that are free of many risks and uncertainties associated with brownfields [138]. This, ultimately, may result in increased land consumption and urban sprawl [139]. Brescia makes no exception in this regard, ranking second among municipalities in Lombardy and among provinces at the national level in terms of total annual land consumption [140]; greenfield sites are being developed, while large brownfields, such as the SIN Caffaro, have remained vacant for decades. The implementation of effective NBSs can be strategic in brownfield redevelopment and the valuing of green urban brownfields, thus contributing to solving a dual land-use policy challenge (reducing the barriers to private-sector redevelopment, for instance, by having positive spillover effects on property values [141,142], while connecting reuse to broader community goals [137]). Despite recent progress and advancements in characterizing the benefits of NBSs and green infrastructure within the academic community [143], it remains challenging for decision makers to incorporate their benefits into urban design and planning [56,71]. Barriers include the need to better embody these concepts within the existing policy mix, providing technical support via trials and best practices, defining appropriate economic mechanisms, and setting effective institutional and governance frameworks [12,14]. This also implies the consideration of innovative financial mechanisms for the development of NBSs and support of their implementation in practice, as a recurring key barrier is obtaining finance, whether public or private [10,12,64]. While NBS could, in principle, be framed within the urban infrastructure domain that traditionally falls within public investments, rapid urbanization and a lack of public funding for urban NBSs may render the involvement of private investors attractive, and sometimes even necessary [64,144]. There are a lot of instruments that local governments can explore to leverage private sources' involvement [145]. Gathering robust data on the benefits delivered by NBSs, including monetary values, is key to informing public decision making on innovative solutions aimed to deliver public goods while attracting potential investors, thus enabling the sharing of costs and risks associated with long-term investments [146], and favoring efficiency while delivering ESs [147].

5. Conclusions

In this study, we estimated—both in biophysical and monetary terms—expected ESs under alternative NBS-based intervention scenarios for the redevelopment and valuing of an urban brownfield within the municipality of Brescia, Northern Italy. Results show that both scenarios improve the ES stock and flows compared to the baseline, thus ensuring a broad range of benefits to local communities. Scenario 1 shows higher values when single ESs are considered, while scenario 2 shows higher total values, as it also accounts

for the phytoremediation capacity ES that is not considered under the first scenario. All in all, regulating ESs represent the bulk of estimated ESs, thus highlighting the potential of proposed NBS solutions for improving urban resilience vis-à-vis existing challenges—such as those posed by the management of a contaminated site, or climate-change-related hazards (e.g., flood risks, rising temperatures, and the urban heat-island effect)—while also considering the increasing societal demand for green spaces within urban settlements.

Although the potential of NBSs as a cost-effective enabler of urban sustainability has been recognized, the implementation, management, and upscaling of NBSs face numerous barriers and challenges. The effective assessment of benefits delivered by urban NBSs represents one of them. The ES assessment and valuation exercise presented within this paper is an example of how research and practice can be integrated to inform urban management activities and provide inputs for future decision making and planning regarding urban developments. The results confirm that existing models and approaches for ES valuation can be effectively used for valuing NBSs, thus contributing to research and practice in setting up a standardized framework for a quick and effective assessment of urban NBSs, both in biophysical and monetary terms.

Despite our efforts, the paper has some limitations. The first includes the a priori selection of ESs and the TEV components targeted by the research, which likely resulted in underestimation of the total value of ESs generated by NBSs under the two intervention scenarios. Future research might aim to enlarge the scope of ESs covered, for instance, by also including phytoremediation capacity in the case of forest projects. A second limitation derives from the combination of traditional estimation approaches and software-based models that required some simplifications or assumptions in modeling, due to technical constraints or data gaps in terms of quality/scale and quantity.

This research is focused on ES supply and does not take into consideration ES demand by potential beneficiaries, which could be explored in future studies. This would allow an exploration of stakeholders' needs and preferences, providing additional inputs for setting priorities in decision-making and planning activities associated with NBS development, as well as in detecting willingness to pay for the benefits generated.

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