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Assessment of regulating ecosystem services generated by green infrastructure: A case study of Bolzano, Italy

Milena V. Sokolova [a,b,*], Brian D. Fath [b,c,d], Elvira Buonocore [a], Pier Paolo Franzese [a]

[a] International PhD Programme / UNESCO Chair “Environment, Resources and Sustainable Development”, Department of Science and Technology, Parthenope University of Naples, Italy
[b] Advancing Systems Analysis Program, International Institute for Applied Systems Analysis, Laxenburg, Austria
[c] Department of Biological Sciences, Towson University, Towson, USA
[d] Department of Environmental Studies, Masaryk University, Brno, Czech Republic

A R T I C L E I N F O

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A B S T R A C T

Sustainable cities is one of the key topics of the United Nations 2030 Agenda for Sustainable Development. SDG 11 promotes the goal that cities should be inclusive, safe, resilient and sustainable human settlements. In this context, urban ecosystems, namely, Green Infrastructure (GI) can play a key role to enhance ecosystem services. GI improves ecosystem functioning and resilience, protects biodiversity, promotes societal health and well-being. The concept of GI in cities is becoming increasingly important in the development of urban policies since it improves the quality of life while mitigating the adverse effects of climate change. In this paper, we integrate biophysical method and monetary methods using i-Tree Eco software with about 12,000 trees within Bolzano, Italy. Model results are given for five assessed ecosystem services: 1) carbon storage, 2) carbon sequestration, 3) oxygen production, 4) avoided runoff, and 5) air pollution removal. Thus, our results show the significance of urban trees as a key element for better urban planning considering specific species contribution. The findings of this study will increase the awareness on the important role GIs play in urban systems to improve human well-being, informing policy-makers in charge of developing strategies to achieve impelling conservation actions and sustainability goals.

1. Introduction

The global urban footprint continues to grow, with more than 55 % of people now living in cities (United Nations: Urban Indicators Database, 2018), the fastest rates of urbanization are shifting from the Global North to the Global South, with significant new construction occurring on previously undeveloped land (Washbourne, 2022). By 2050, the global population is estimated to be 30 % higher than it is today, at around 9.8 billion (Directorate-General for Climate Action (European Commission), 2018(European Commission, D.-G, 2016; Pulighe et al., 2016). And, the urban population is expected to rise to 68 % by that time (United Nations Human Settlements Programme, 2022).

Concerns about the sustainability of cities and urban areas have emerged accordingly, as witnessed by, among others, the 2030 Agenda for Sustainable Development (explicitly SDG 11 (United Nations, 2018); the world Forum on Urban Forests (FAO, 2018); and

* Corresponding author at: Parthenope University of Naples, Villa Doria d’Angri, Via Francesco Petrarca, 80, 80123 Napoli, Italy.
E-mail address: milena.sokolova001@studenti.uniparthenope.it (M.V. Sokolova).

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the UN New Urban Agenda (Masiero et al., 2022). As the world's population increasingly becomes urban, challenges such as maintaining a high quality of life and adapting to climate change arise (Dodman, 2009; Ugochukwu et al., 2024). At the international scale, assessing urban vulnerability to climate change is an emerging research topic. This is evidenced by projects such as "Engineering Cities: How Can Cities Grow While Reducing Vulnerability and Emissions?" (Tyndall Centre, UK), "Urban Lifestyles, Sustainability, and Integrated Environmental Assessment" (Potsdam Institute for Climate Impact Research, Germany), and the "New York Climate and Health Project" (Masson et al., 2014).

As part of urban policies, urban green infrastructure (UGI) has become increasingly important (Vasilescu et al., 2022). Green infrastructure can help provide ecosystem services and protect biodiversity (Baklazhenko and Roshchupkina, 2020; Jato-Espino et al., 2023). In a broad sense, ecosystem services (ES) are understood as the benefits that a person receives from the functioning of natural ecosystems (Bukvareva and Z. D, 2016). Healthy ecosystems are the cornerstone of sustainable cities, shaping human well-being and driving much of the economic activity (Mader et al., 2011a).

Occupying a minimal area, cities nevertheless have a disproportionately significant impact on the biosphere due to the large population and economic development. This reliance on ecosystem services underscores the interconnectedness of urban areas and natural environments. Most of the ecosystem services consumed by urban residents are produced by ecosystems located not only outside the city boundaries, but over a much larger area at a great distance from the city (Elmqvist and Mcdonald, 2013; Ecosystem Services of Russia, 2021). It is historically the case that urbanization has caused a major decline in natural habitats, directly impeding progress toward the Aichi Target 5 of the Convention on Biological Diversity, which is to at least halve the rate of habitat destruction and reduce it to zero wherever possible (Convention on Biological Diversity, 1992).

At the city scale, Green Infrastructure (GI) is defined as a strategically planned network of natural and semi-natural areas, along with other environmental features, that is designed and managed to provide a wide array of ecosystem services (European Commission, D.-G, 2016; European Environment Agency, 2006). It includes green spaces (or blue spaces when referring to aquatic ecosystems) and other physical elements in both land (including coastal regions) and marine environments. By linking urban and rural areas, green infrastructure (GI) creates attractive living and working environments. Green infrastructure is one of a number of terms increasingly used to describe, formally and informally, the aforementioned benefits that humans derive from the natural environment, in an economic and non- economic sense, in order to support environmental decision-making (European Union, 2018; Washbourne, 2022). For example, GI could help manage floods, heat stress, water scarcity, carbon storage, energy use, groundwater recharge, erosion, well-being, ecological connectivity, environmental education, aesthetics, food production, or green job opportunities. Despite their diversity, most of them can be organized and understood as ES. There are multiple reviews on the potential of GI to increase urban resilience, especially against floods and the Urban Heat Island effect (Jato-Espino et al., 2023).

The condition of urban ecosystems affects human well-being, biodiversity, and the way cities impact their surroundings. Gaining a deeper understanding of urban ecosystems will enable us to design more livable cities that offer high-quality habitats for both humans and other species (Zulian et al., 2022a, 2022b).

Also, for example, air quality improvement by urban vegetation can reduce health problems and mortality (Russo et al., 2016a, 2016b; Zulian et al., 2022a, 2022b). The significance of nature in urban areas is now widely acknowledged. In the study of (Preston et al., 2024), it was found that parks offer three times more benefits compared to brownfields overall. In suburban and peri-urban areas, parks contribute significantly more to regulating ecosystem services. Moreover, urban ecosystems play a crucial role in achieving biodiversity conservation goals (Zulian et al., 2022a, 2022b). The extent of urban green is reported as a percentage of the city area (% of urban green) or as a metric per resident (Rayan et al., 2022; Zulian et al., 2022a, 2022b).

The Millennium Ecosystem Assessment categorized ES into four groups: provisioning, regulating, and cultural services that directly affect people and supporting services needed to maintain the other services (Millennium Ecosystem Assessment (Program), 2005a). However, the more recent Common International Classification of Ecosystem Services (CICES) excludes supporting services from its classification (Paudel and States, 2023). Urban green spaces provide several key provisioning, regulating, cultural and supporting ecosystem services (Table 1).

Unlike traditional environmental services, these urban-focused ES, such as air purification, noise reduction, and recreational activities (Table 1), are particularly valuable in densely populated areas where natural landscapes are limited. By mitigating urban stressors and enhancing overall well-being, these services play a crucial role in adapting cities to the challenges posed by rapid urbanization and environmental change (Veerkamp et al., 2021). For our scope of work, we assessed the highlighted regulating ecosystem services from Table 1.

Table 1
Ecosystem services provided by UGI that are relevant to human health – (Mader et al., 2011b; Millennium Ecosystem Assessment (Program), 2005b; Salmond et al., 2016).

Service class	Service meaning	Service examples
Provisioning Services	Products obtained from ecosystems.	Food supply, water supply.
Regulating Services	Benefits obtained from regulation of ecosystem processes.	<u>Air quality regulation</u>, noise reduction, <u>climate regulation,</u> water regulation, pollination, pest regulation, seed dispersal, <u>runoff mitigation,</u> urban temperature regulation.
Cultural Services	Nonmaterial benefits obtained from ecosystems.	Recreation, aesthetic benefits, cognitive development, place values and social cohesion.
Supporting Services	Needed to maintain the other services.	Habitat for biodiversity.

These ecosystem services offer substantial benefits to both human well-being and natural systems. They help mitigate heat stress, lower the risk of flooding during heavy or prolonged precipitation, and enhance air quality while reducing associated health risks. Additionally, they support mental health by fostering opportunities for recreation and aesthetic enjoyment, deepening our connection with nature (Veerkamp et al., 2021).

Cities rely on a healthy natural environment to consistently provide a variety of benefits or ecosystem services (Mader et al., 2011a). These services encompass the numerous advantages that nature offers to society (FAO, 2018). Green infrastructures are currently the most effective NBS for sustainable cities (Pinto et al., 2023; Wong et al., 2018).

The goal of the study is to investigate the role of GI in urban areas and to quantitatively assess its ability to provide a diverse range of ES that contribute to human health and well-being.

The following research questions were set:

1) How does the integration of ecosystem services and green infrastructure contribute to urban sustainability and resilience?
2) What is the role of specific urban tree species in enhancing environmental quality?

2. Materials and methods

2.1. Study area

The evaluation of ecosystem services related to green infrastructure was carried out in a case study of Bolzano (46°30′N 11°21′E),

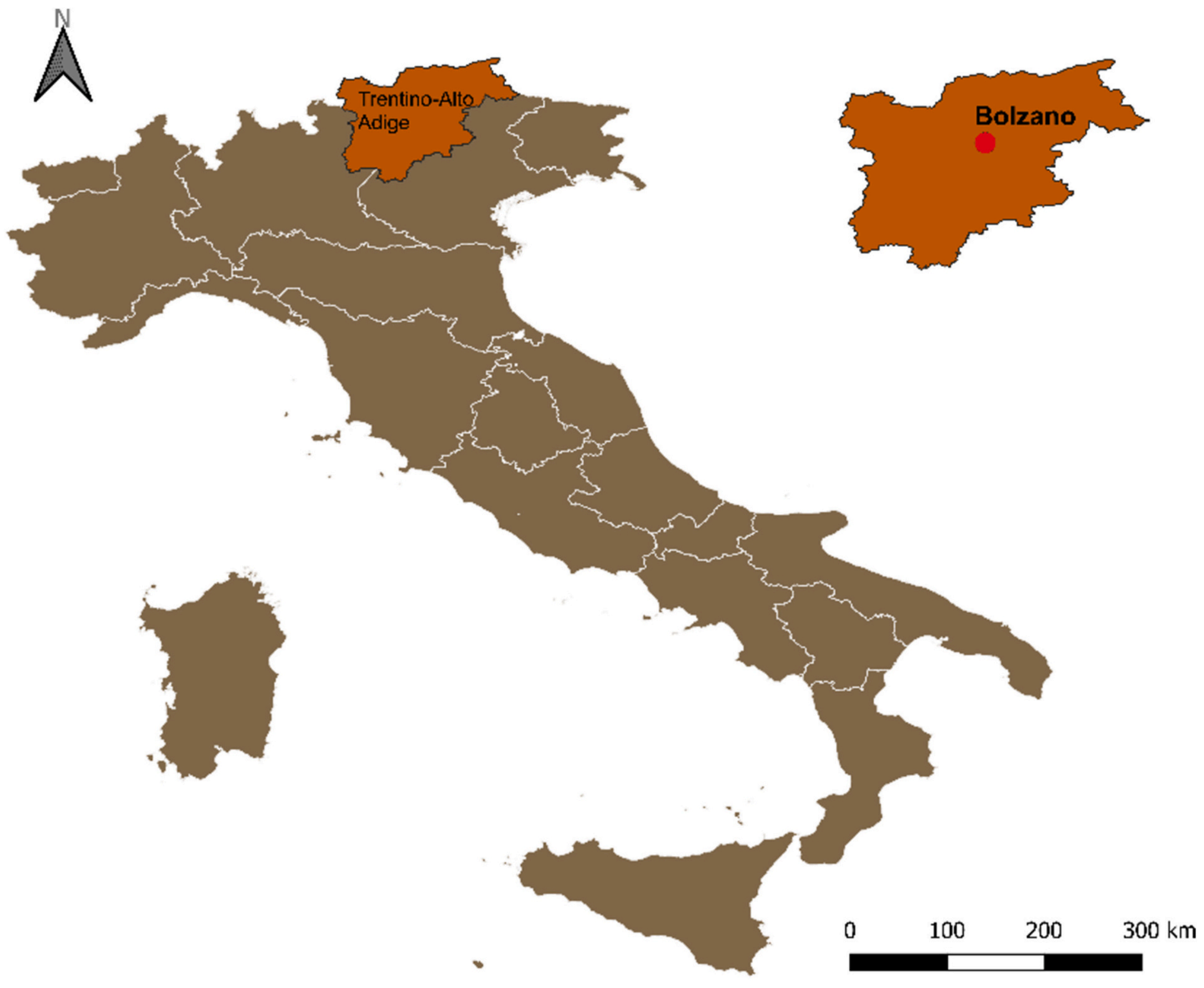

Fig. 1. Location of case study.

Table 2
Summary of Bolzano's population by species (U.S. Forest Service, N. R. S, 2023).

Tree Species	Percentage (%)	Leaf Type
Norway Maple *(Acer platanoides)*	4.6	Deciduous
Sweetgum *(Liquidambar styraciflua)*	4.0	Deciduous
Downy Oak (*Quercus pubescens)*	3.1	Deciduous
Littleleaf Linden *(Tilia cordata)*	3.1	Deciduous
Sycamore spp. *(Platanus)*	2.9	Deciduous
Cherry Plum *(Prunus cerasifera)*	2.8	Deciduous
Sycamore Maple *(Acer pseudoplatanus)*	2.8	Deciduous
Arizona Cypress *(Cupressus arizonica)*	2.7	Evergreen
Italian Cypress (*Cupressus sempervirens)*	2.5	Evergreen
European Hackberry *(Celtis australis)*	2.3	Deciduous
Other	69.10	–

the capital of South Tyrol in northern Italy. Bolzano is the largest city in South Tyrol with a population of 106,107 and covers an area of 52.3 km^2 (Ufficio Statistica e Tempi della Città, 2023) (Fig. 1).

The city was chosen due its unique climate and geographical location, which includes diverse urban vegetation. Bolzano experiences a semi-continental climate characterized by hot summers and cold winters. The varied altitudes and favorable conditions in the area foster a remarkable range of vegetation, from sub-Mediterranean flora to high-mountain species (Eurac Research, 2018).

The mix of trees in Bolzano originate from different continents (Appendix A). For the four city districts - *Centro Piani Rencio, Europa Novacella, Don Bosco and Gries S.Quirino* – the trees are mainly from Europe & Asia with the following percentage *24.3; 29; 27.80; 36.20*, respectively. Only the district - *Oltrisarco Asiago* - is different with trees mostly from North America (*30.10 %*). There are no trees in Bolzano from South America and insignificant number of trees from Oceania, which are present only in Europe Novacella district. But, we observed there are a lot of trees from Africa in all city districts which confirms Bolzano's susceptibility due to geographical position. The study of (Taylor and Jones, 2012) estimate that Trento region has the third highest density of non-native spevies, after

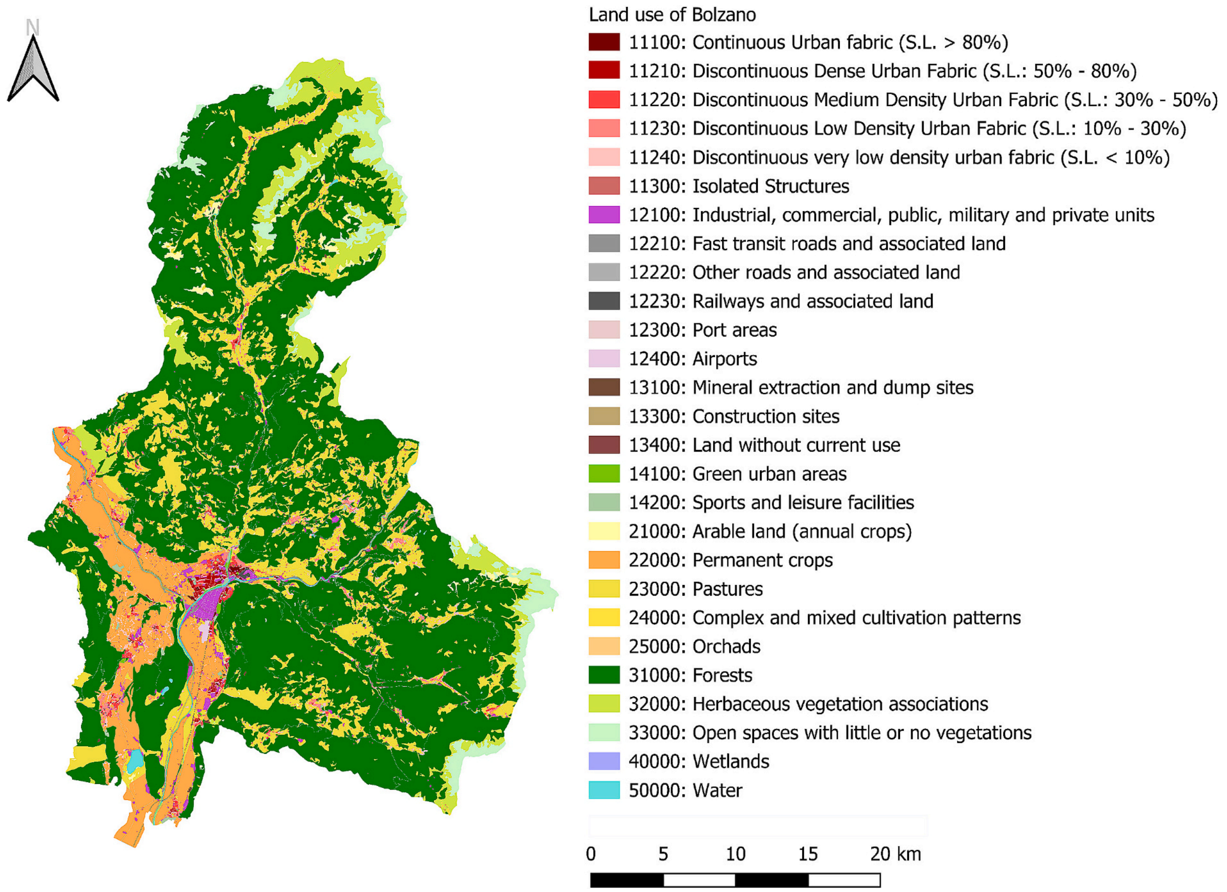

Fig. 2. Land classes of Bolzano (Copernicus Land Monitoring Service. Urban Atlas.).

two other Northern regions - Lombardia and Veneto. Table 10 in Appendix A shows place of native range in more detailed.

Bolzano urban trees are mostly deciduous (Pace et al., 2018), broadleaf trees (80.98 %) compared to evergreen (19.02 %). The most dominant species are Norway Maple *(Acer platanoides)*, Sweetgum *(Liquidambar styraciflua)*, and Downy Oak (*Quercus pubescens)* (Table 2).

Specific geographical position explaines the diversity of urban forests in Bolzano which are composed of a mix of native and exotic tree species (Provincia Autonoma di Bolzano - Alto Adige, 2023). Fig. 2 presents the land use classes across Bolzano. This classification highlights key areas of green infrastructure, like forests, green urban areas and arable land, which serve as critical habitats for diverse plant species.

Bolzano, the largest city in South Tyrol, is situated in the Adige Valley in the eastern Italian Alps. This valley exemplifies the features of mountain valley environments, with thermally driven circulations like valley and slope winds that shape meteorological conditions in the warmer months. During colder months, thermal inversions often occur at the valley floor, affecting local air quality and cloud formation. These unique climatic conditions influence biodiversity, supporting a wide range of vegetation types in Bolzano, including both native and exotic tree species.

The region's biodiversity is also shaped by the presence of invasive plant species. In South Tyrol, approximately 84 % of plant species are classified as native, while 16 % are neophytes, of which 32 species are considered invasive, posing a significant threat to local biodiversity (Lazzaro et al., 2020; Comune di Bolzano, 2023). Invasive plant species are typically defined by their robustness, adaptability, high reproductive potential, and the absence of natural predators. These abilities enable them to displace native plants and make them a threat to natural areas (U.S. Forest Service, N. R. S, 2023).

The urban forests in Bolzano comprise a combination of indigenous and non-native tree species. Because of this, urban forests often boast greater tree diversity than their natural surroundings. While this increased diversity can reduce the overall impact of species-specific insects or diseases, it can also pose a threat to native plants if non-native species become invasive and displace native species (Whitman and Wilkerson, 2014). There are only about 12 % of trees that are native to Europe. Most trees have an origin from Europe & Asia (30 % of the trees) (Appendix A).

2.2. Data analysis

Comune di Bolzano (Comune di Bolzano, 2023) keeps meticulous records of all urban trees within their municipality, with tags cross-reference (Fig. 3) to information indicating the species, age, diamter at breast height (DBH), and height of the tree (Comune di Bolzano, 2023).

The current dataset has more than 12,000 trees of which 11,948 were extracted and assessed on June 2023 due to required input availability (Comune di Bolzano, 2023). In our work, we used coordinates which indicates Tree-ID with label on it which allowed us to find a tree not only in cadastre but also in the city if needed.

In this work, the city was stratified by districts because that function allowed us to compare urban forest effects between each stratum and for this reason the research on a city is more accurate. Other benefit is a support of effective policymaking as cities often have different policies and plans for each district (City of Copenhagen, 2021). Stratifying by districts allows urban planners and policymakers to make targeted decisions about tree planting and green infrastructure development. This approach aligns with achieving SDG goals and could support the objectives outlined in the (OECD, 2023) report.

Tree density by districts (Table 3) ranges from about 78 to 148 trees per hectare. Higher tree density can lead to more competition for resources (light, water, nutrients), potentially limiting the growth (Rozendaal et al., 2020), and some ecosystem services potential of each tree, such as carbon sequestration and avoided runoff.

As shown in Fig. 4, in our research we used a variety of input variables and processes to estimate ES provided by urban trees. Each of these variables is crucial for accurately modeling the ecosystem services provided by trees. For instance, the species and size of a tree determine its leaf area, which is essential for calculating the amount of air pollution the tree can remove.

Fig. 3. Tree ID (labels) on trees of Bolzano (Tree N°1 and N°2).

Table 3
Number of trees by city districts (Comune di Bolzano, 2023, U.S. Forest Service, 2023).

ID	Description	Area (ha)	N of Trees	Tree density
1	Centro Piani Rencio	19.87	1558	78.42
2	Oltrisarco Asiago	21.16	3136	148.19
3	Europa Novacella	16.95	1371	80.88
4	Don Bosco	24.41	2485	101.82
5	Gries S.Quirino	43.39	3398	78.28
TOTAL		**125.78**	**11,948**	

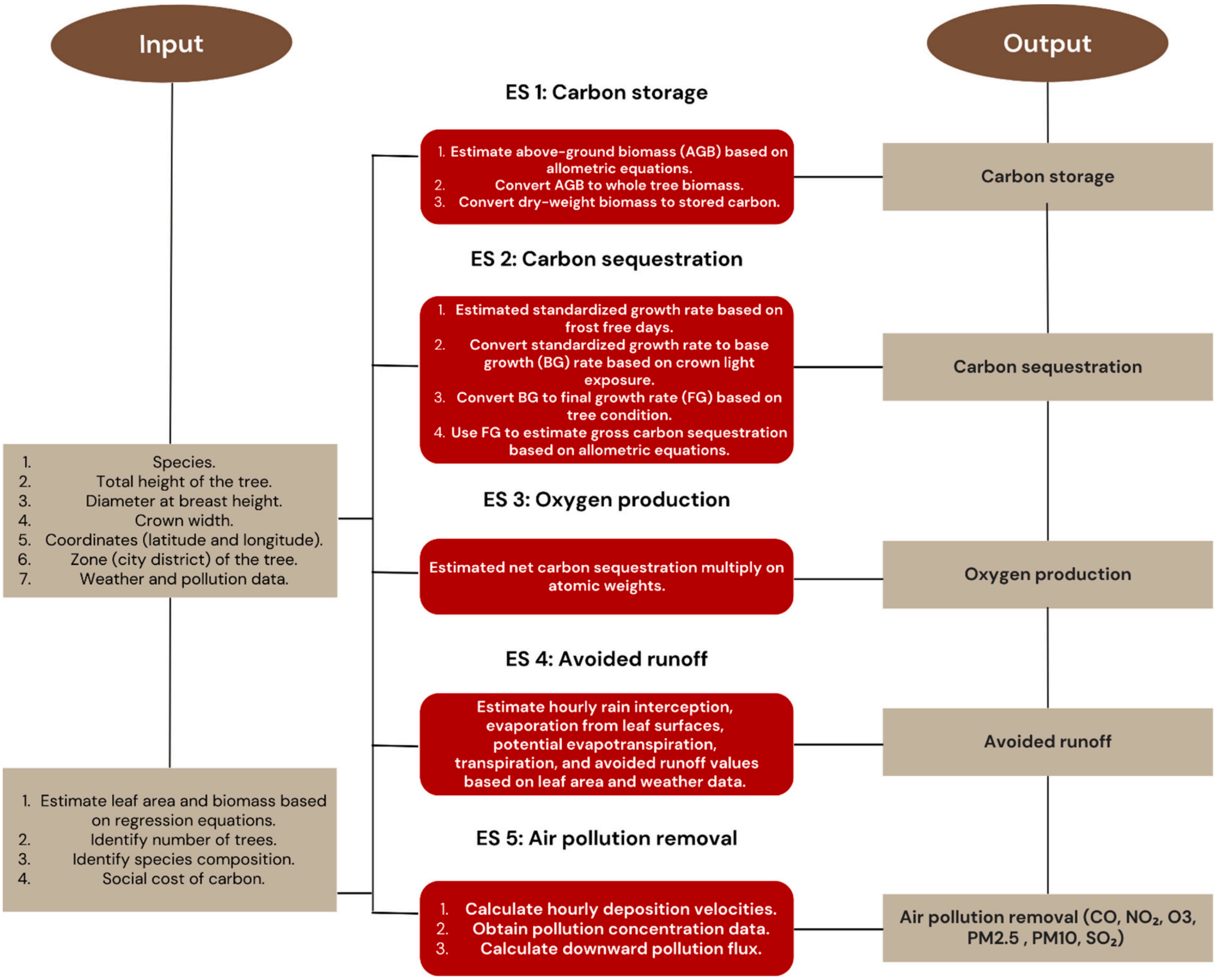

Fig. 4. Input variables and processes.

The ecosystem services quantified by i-Tree Eco, as illustrated in the figure, provide significant benefits to urban areas. In our analysis, the services include:

- **Carbon storage and sequestration**: Trees act as carbon sinks, helping to mitigate climate change.
- **Oxygen production**: Trees produce oxygen through the process of photosynthesis, contributing to the overall oxygen supply.
- **Avoided runoff**: Trees reduce stormwater runoff, decreasing the burden on urban drainage systems.
- **Air pollution removal**: Trees improve air quality by absorbing pollutants through their leaves.

2.3. Brief presentation of i-Tree eco software

For the purpose of this research, analysis was done to assess the benefits of urban trees in Bolzano in both biophysical and monetary terms using i-Tree Eco Software v6.0.32. The model used tree measurements and other data to estimate ecosystem services and structural characteristics of the urban forest (i-Tree, 2021).

i-Tree Eco estimated the hourly dry deposition of CO, NO_2, O_3, $PM_{2.5}$, PM_{10} and SO_2 throughout the year based on tree, shrub and grass cover data, hourly National Climatic Data Center (NCDC) weather data. Lost hourly contamination information were filled in based on strategies point by point in (Hirabayashi and Endreny, 2016). (Hirabayashi, 2017) provided detailed information on the quality of weather station data. Daily particulate matter data were used as hourly inputs (i.e., daily average was used for each hour of the corresponding day). If multiple monitors exist, the average of all monitor data were used. Missing hourly pollution data were filled in based on procedures detailed in (Hirabayashi and Kroll, 2017).

In this study, all equations for Bolzano city were done using i-Tree Eco modeling.

2.3.1. Carbon storage and carbon sequestration

Carbon storage—the amount of carbon bound up in the above-ground and below-ground parts of woody vegetation—was calculated for each tree using equations from the literature and measured tree data. Open-grown, maintained trees generally exhibit less biomass than what is predicted by forest-based biomass equations (Nowak et al., 1994). To account for this discrepancy, the biomass results for open-grown urban trees were adjusted by multiplying by 0.8. No adjustments were made for trees in natural stand conditions. Tree dry-weight biomass was changed over to put away carbon by applying 0.5 (Chow and Rolfe, 1989) or 0.41 factor for palm trees (Sanquetta et al., 2015). To avoid overestimating carbon storage for very large trees, the total carbon sequestration was capped at 40 kg C per cm diameter at breast height (DBH) growth once a tree accumulates 7500 kg of carbon in i-Tree Eco and Forecast.

To estimate the total amount of carbon sequestered each year, the average diameter growth of trees—categorized by genus, diameter class, and health condition—was added to the existing tree diameter for a given year (year x) to project the tree's diameter and carbon storage for the following year (year x + 1) (Nowak et al., 2014a, 2014b). The efficiency of annual carbon sequestration, which indicates the yearly carbon absorption capacity, can be determined using i-Tree Eco. This calculation takes into account factors such as tree size, health, canopy coverage, and spatial distribution (de Manuel et al., 2021).

Annual gross carbon sequestration was estimated by incrementally increasing the tree's DBH in the computer model, based on an estimated annual growth rate. The carbon storage in the current year (year 0) was then contrasted with carbon storage in the next year (year 1) to estimate the annual sequestration. If a living tree's carbon storage was over 7500 kg, then carbon sequestration for these large trees was estimated based on the sequestration rate (kg/cm DBH growth) when the tree reached 7500 kg C storage. A maximum sequestration rate was set at 40 kg/cm DBH growth if the tree's storage was greater than 7500 kg. These sequestration values were added to the storage value annually, so storage can exceed 7500 kg, but the sequestration rates are prevented from growing geometrically based on carbon equations applied to large trees. Tropical biomass equations from wet, moist, and dry tropical forests (Chave et al., 2005) were used in tropical areas instead of current biomass equations.

2.3.2. Oxygen production

The amount of oxygen produced was estimated from carbon sequestration by using atomic weights:

$$\boldsymbol{net\ O2\ release}\ (\boldsymbol{kg/yr}) = \boldsymbol{net\ C\ sequestration}\ (\boldsymbol{kg/yr})^{*}\mathbf{32/12} \tag{1}$$

To estimate the net carbon sequestration rate, the carbon sequestered through tree growth was adjusted for losses due to tree mortality. Consequently, the net carbon sequestration and net annual oxygen production of the urban forest take decomposition into account (Nowak et al., 2007). For complete inventory projects, oxygen production was estimated from gross carbon sequestration and does not account for decomposition.

2.3.3. Avoided runoff

Using leaf and bark area data along with local hourly weather information, i-Tree Eco estimated hourly values for rain interception, leaf surface evaporation, potential evapotranspiration, transpiration, and avoided runoff. These process-based calculations were simulated individually and then linked with other processes. For example, interception was simulated using an improved Rutter methodology (Valente et al., 1997). Estimates are generated based on current tree conditions and then without trees in order to estimate the impact of trees on surface runoff. Impervious cover beneath trees was assumed to be 25.5 %, the national average impervious cover (Nowak and Greenfield, 2012). To estimate the effects of individual trees, the overall water impacts across the entire tree population were allocated to each tree based on its leaf area.

Multiple calculations were carried out to determine hourly values for rain interception, evaporation, transpiration, potential evapotranspiration, and avoided runoff. These equations and methods are detailed in (Hirabayashi, 2013, 2015, 2016; Wang et al., 2008; Yang et al., 2011).

2.3.4. Air pollution removal

With urbanization, air pollution is increasing. Air pollution poses a clear hazard to human health, especially to people suffering from respiratory diseases (Zhao et al., 2023). Air pollution removal and value estimates were based on procedures detailed in Nowak et al. (2014). This process used local tree cover, leaf area index, percentage evergreen trees, weather, pollution, and population data to estimate pollution removal (g/m^2 tree cover) and values ($euro/m^2$ tree cover) in urban areas for each county. These values were applied to the area of tree cover to determine estimated removal and associated values of carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter less than 2.5 μm ($PM_{2.5}$), particulate matter between 2.5 and 10 μm (PM_{10}), and sulfur dioxide (SO_2). The model simulations were conducted in 2015 using hourly meteorological data registered at the Bolzano Dolomiti Airport NCEI ID: 160200–99,999 (coordinates: 46.460, 11.326).

Thus, air pollution removal for 6 pollutants were estimated with following calculations:

Pollution removal, or downward pollutant flux, is determined by the equation (in $g/m^2/s$):

$$\boldsymbol{F} = \boldsymbol{Vd}^{*}\boldsymbol{C}, \tag{2}$$

Where.

V_d = deposition velocity (m/s), and.

C = pollutant concentration (g/m^3).

Deposition velocity was calculated as (Baklazhenko and Roshchupkina, 2020):

$$\boldsymbol{Vd} = \mathbf{1}/(\boldsymbol{R_a} + \boldsymbol{R_b} + \boldsymbol{R_c}), \tag{3}$$

Where.

R_a = sum of the aerodynamic boundary layer,

R_b = quasi-laminar boundary layer, and.

R_c = canopy resistances.

Hourly gauges of air resistance factors, R_a and R_b were determined using *standard resistance equations* (Killus et al., 1984; Nowak et al., 1998; Pederson et al., 1995) and *hourly weather data*. The effects of R_a and R_b were significantly smaller than those of R_c. The calculations of air pollution removal and its associated values were based on the methods outlined in (Nowak et al., 2014a, 2014b). This process used local tree cover, leaf area index (the ratio between the total foliage area and the ground area under the canopy (Ungaro et al., 2022)), percentage evergreen trees, weather, pollution, and population data to estimate pollution removal (g/m^2 tree cover) and values ($euro/m^2$ tree cover) in urban areas for each county. These values were applied to the area of tree cover to determine estimated removal and associated values of carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter less than 2.5 μm ($PM_{2.5}$), particulate matter between 2.5 and 10 μm (PM_{10}*), and sulfur dioxide (SO_2).

3. Results

Our results are presented in both biophysical and monetary terms using i-Tree Eco software. However, we are aware that some results from i-Tree Eco may be underestimated. To address potential understimation, we applied a recent monetary evaluation methodology from (European Environment Agency, 2024) to one ES—air pollution removal—as an example, in order to demonstrate the significance of the results.

3.1. Carbon storage

For this analysis, trees of Bolzano store about 5160.59 tons of carbon (Fig. 5) with an economic value of € 375,000. Among these the dominant specie in carbon storage is deodar cedar with 551.80 tons per year. The next important species are *Sycamore spp* and *Siberian*

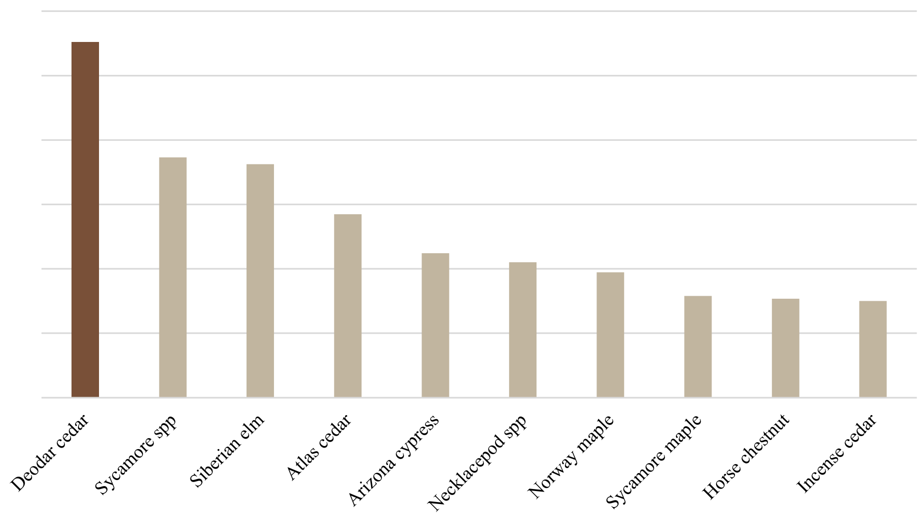

Fig. 5. Estimated carbon storage for urban tree species with the greatest storage (tons).

elm with not a big difference between them at 373.00 and 362.60 tons, respectively.

3.2. Carbon sequestration

Carbon sequestration refers to the process by which plants remove carbon dioxide from the atmosphere.

Total biophysical value is about 73.02 tons per year (Fig. 6) with an associated value of of € 5300. The data analysis showed Deodar cedar sequestreted most carbon with 4.48 tons per year.

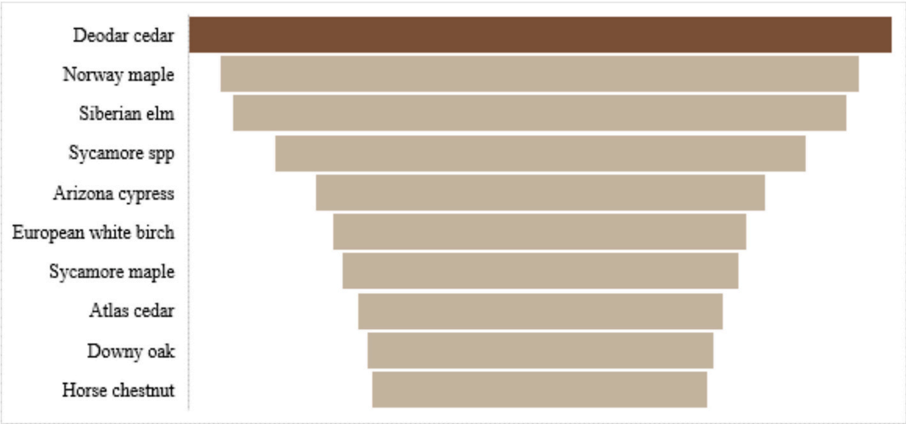

Fig. 6. Estimated annual gross carbon sequestration for urban tree species with the greatest sequestration (tons).

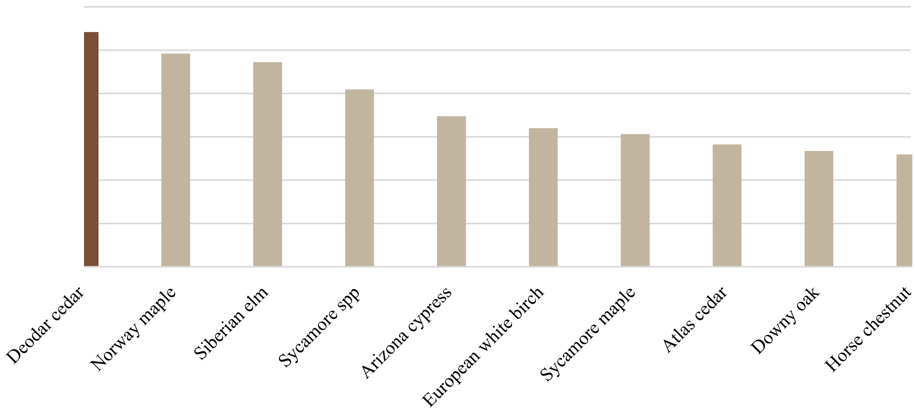

Fig. 7. Oxygen production by individual species (kg/yr).

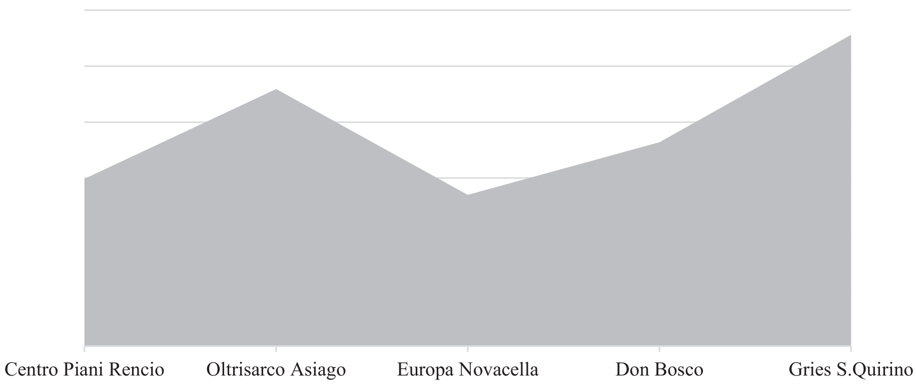

Fig. 8. Oxygen production by city districts (ton/yr).

3.3. Oxygen production

Urban trees are frequently recognized for their role in oxygen production. The yearly oxygen output of a tree is closely linked to the quantity of carbon it stores, a factor that is influenced by the tree's growth and accumulation. Trees of Bolzano are estimated to produce 194.80 tons of oxygen per year. The dominant specie in oxygen production is Deodar cedar with 10,838.1 kg per year value (Fig. 7). However, the contribution of trees to oxygen levels is relatively minor due to the vast and consistent supply of oxygen in the atmosphere, as well as substantial production from aquatic ecosystems (Broecker, 1970).

We assume oxygen production is not presented in monetary terms in i-Tree Eco because carbon sequestration is already valued. Since both services are joint outcomes of photosynthesis, including oxygen production could lead to concerns about double counting (Chen et al., 2022).

As an example, we presented results by city districts for this ecosystem service to aid urban planning and provide useful insights for policymakers. Fig. 8 shows oxygen production in tons per year by districts. The Gries S. Quirino district has the highest annual oxygen production at 55.60 tons per year, while Europa Novacella has the least at 27 tons per year, primarily due to differences in tree population per hectare. These findings suggest that targeted planting in districts like Europa Novacella and Centro Piani Rencio could enhance their oxygen production capacity, thereby contributing to better air quality and overall urban health.

3.4. Avoided runoff

Surface runoff is a significant concern in many urban areas, as it can introduce pollutants into streams, wetlands, rivers, lakes, and oceans. When it rains, some of the precipitation is captured by vegetation like trees and shrubs, while the rest reaches the ground. The portion that doesn't infiltrate into the soil becomes surface runoff (Hirabayashi, 2013). In urban environments, the prevalence of impervious surfaces leads to increased surface runoff. However, urban trees and shrubs help mitigate this issue by intercepting precipitation and encouraging soil infiltration and water storage through their root systems. Avoided runoff is estimated based on local weather of Bolzano. The trees and shrubs of Bolzano help to reduce runoff by an estimated 8019.97 m^3/yr (Fig. 9), assuming total annual precipitation was 51.9 cm. Avoided runoff value is calculated by the price €2.361/m^3 and total value per year is 18,932.27 € (Table 4).

Annual avoided surface runoff is determined by calculating the difference in runoff with and without vegetation, focusing on how much rainfall is intercepted by vegetation. While tree leaves, branches, and bark can all intercept precipitation and help reduce surface runoff, this analysis only considers the precipitation intercepted by leaves.

3.5. Air pollution removal

In total, the model indicates that Bolzano trees removed around 3 tons of air pollution (ozone, carbon monoxide, nitrogen dioxide, particulate matter less than 2.5 μm, particulate matter less than 10 μm and greater than 2.5 μm, and sulfur dioxide) per year.

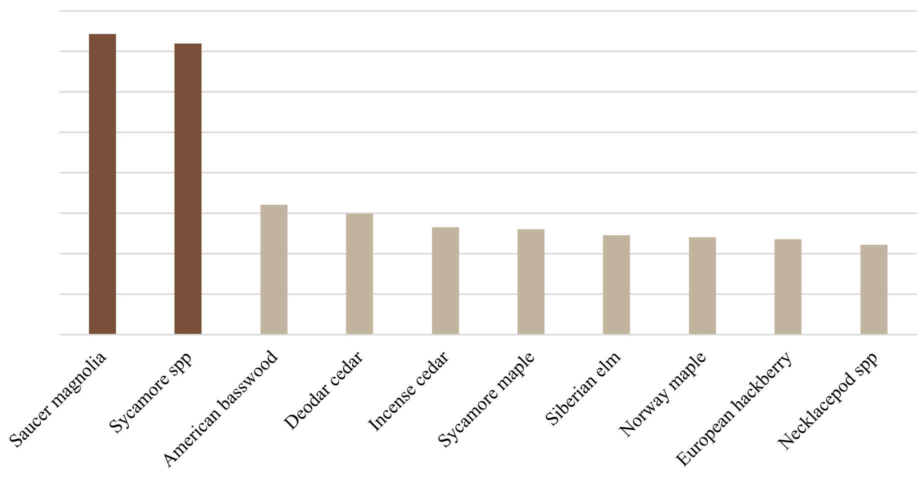

Fig. 9. Avoided runoff by species (m^3/yr).

Table 4
The greatest impact of the first tree species on stormwater mitigation.

Species Name	Number of Trees	Leaf Area (LAI) (ha)	Water Intercepted (m^3/yr)	Avoided Runoff (m^3/yr)	Avoided Runoff Value (€/yr)
Saucer magnolia	108	28.30	3671.87	742.22	1752.12
Sycamore spp	346	27.43	3558.09	719.22	1697.82
American basswood	168	12.25	1589.77	321.35	758.60
Deodar cedar	254	11.39	1477.78	298.71	705.16
Incense cedar	242	10.13	1314.61	265.73	627.30
Sycamore maple	330	9.92	1286.37	260.02	613.82
Siberian elm	168	9.37	1215.34	245.67	579.93
Norway maple	548	9.15	1186.76	239.89	566.29

Table 5
Annual air pollution removal in biophysical and monetary terms by urban trees and shrubs.

Air pollutant	Biophysical removal (kg/yr)	Economic removal (€/yr)
CO	133	ND
NO_2	801	28,513.197
O_3	1718	61,155.646
PM_{10}	222	34,261.26
$PM_{2.5}$	3.32	630.219
SO_2	32	1395.104

The removal of these pollutants by urban trees and shrubs provides substantial environmental and public health benefits. From Table 5 we can see, the significant removal quantities were for 3 pollutants: O_3, NO_2, $PM_{10.}$ Removing 1718 kg of ground-level ozone (O_3) improves air quality and reduces health risks, leading to fewer cases of asthma and respiratory issues and lowering healthcare costs. The reduction of 801 kg of nitrogen dioxide (NO_2) helps mitigate the formation of smog and acid rain, protecting ecosystems, water bodies, and buildings, while also improving air quality and decreasing respiratory and cardiovascular diseases among the population. Additionally, the removal of 222 kg of particulate matter (PM_{10}) prevents environmental degradation and reduces respiratory and cardiovascular diseases, especially benefiting vulnerable groups like children and the elderly (Kelly et al., 2021; Laumbach et al., 2015).

Moderate removal quantites were for CO and SO_2. The removal of 133 kg of carbon monoxide (CO) by urban trees and shrubs improves overall environmental health by reducing this harmful gas that can affect animals and ecosystems, while also decreasing the risk of CO poisoning and enhancing air quality, leading to better health outcomes (U. S. Environmental Protection Agency EPA, 2023). Similarly, the reduction of 32 kg of sulfur dioxide (SO_2) helps protect forests, soils, and aquatic habitats from acid rain damage, and benefits people by lowering respiratory problems, particularly for those with asthma and chronic respiratory diseases (U. S. Environmental Protection Agency EPA, 2023). Although only 3.32 kg of particulate matter ($PM_{2.5}$) is removed, even this small amount is significant because $PM_{2.5}$ particles are highly harmful; their reduction leads to substantial health benefits, including lower rates of heart attacks, strokes, and respiratory diseases (Apte et al., 2018).

Initially, we assessed the economic value of air pollution removal using i-Tree Eco software, estimating €14,131 per year for six pollutants. To provide a valuation that better reflects recent advancements and policy relevance, we applied the updated EEA methodology (European Environment Agency, 2024), which uses coefficients based on marginal damage costs (€2021/t) for major pollutants, accounting for their impacts on health, ecosystems, and materials. We used the coefficients for each pollutant as indicated in the methodology, but for ozone, we applied the NOx coefficient, assuming its value to be the same as that of its precursor, NOx (Fusaro et al., 2017).

While CO is excluded from the EEA calculation, the resulting value for Italy was €125,955.4 per year (Table 5) —substantially higher than the i-Tree estimate, highlighting the broader significance of these services for stakeholders.

Knowing that *Saucer magnolia* and *Sycamore spp* are not the most dominant in Bolzano city, however, they absorbed the most pollution for all 6 pollutants (Fig. 10). We found that the enhanced air pollution removal in Bolzano is influenced by several factors,

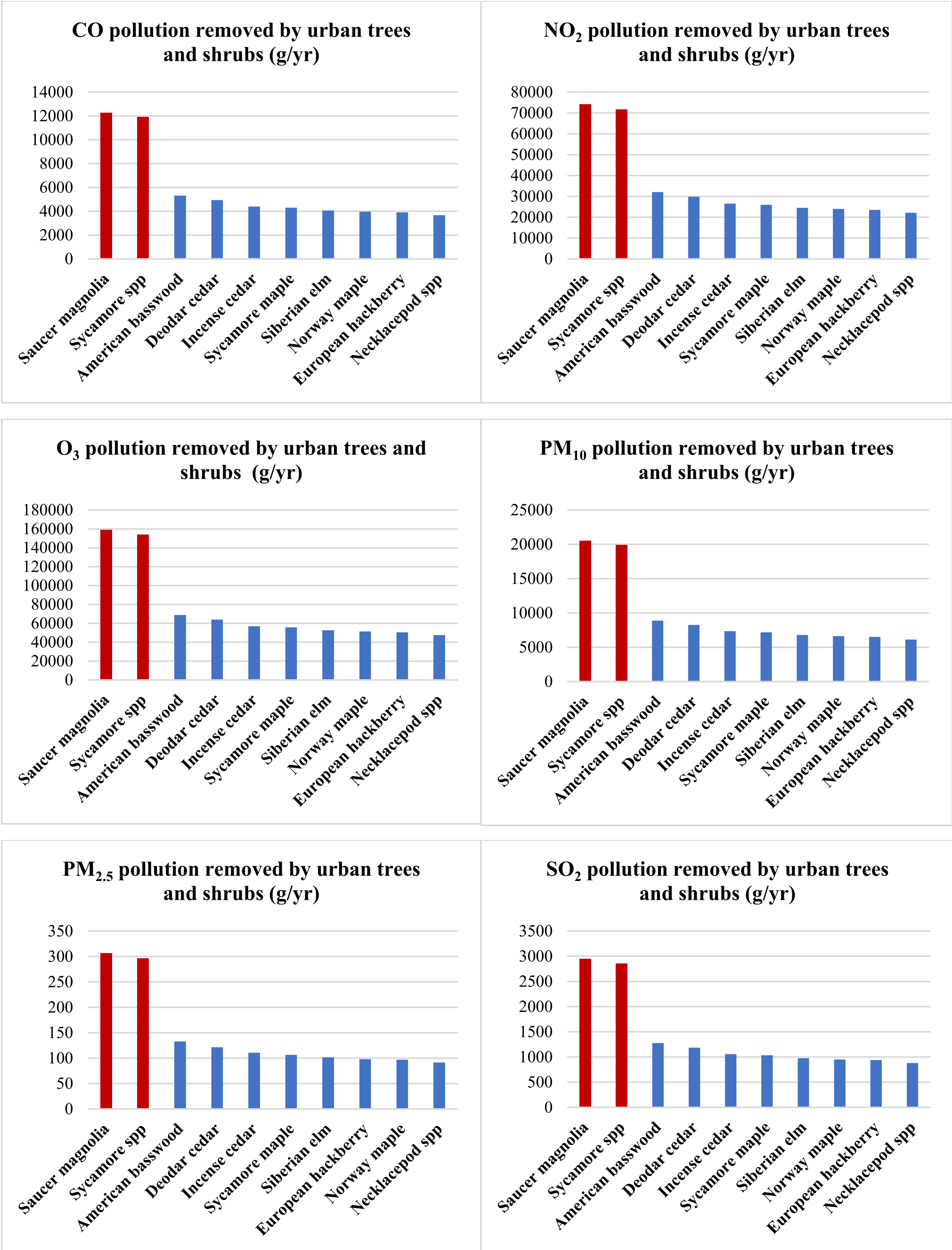

Fig. 10. Detailed pollution removed by 10 best individual species.

Table 6
Leaf biomass of trees by species (U.S. Forest Service, 2023).

Species	Leaf Biomass (ton)
Saucer magnolia	20.80
Sycamore spp	13.90
Necklacepod spp	8.10
Sycamore maple	7.60
Siberian elm	7.00
Littleleaf linden	6.30
Downy oak	6.20
European hackberry	5.80
Horse chestnut	5.60
Norway maple	5.40

including climate, pollution levels, healthy leaf surface area, and the diameter at breast height (DBH) of the trees within the modeled population. Among the species studied, Saucer Magnolia and Sycamore spp. are the most dominant in terms of leaf biomass, with 20.80 and 13.90 tons, respectively (Table 6).

4. Discussion

Results of this study showed the importance of trees in urban areas. According to the (Huuskonen et al., 2021), diverse vegetation enhances ES output while also promoting greater biodiversity, as demonstrated in our case study of Bolzano. Oxygen production, although an important ecosystem service in natural systems, was excluded from the discussion due to its relatively low contribution in this study (194.80 tons per year). Additionally, oxygen production does not always meet the criteria of an ecosystem service in urban environments. For this reason, no economic value was assigned to this service in our analysis. Ecosystem services such as carbon storage, carbon sequestration, avoided runoff and air pollution removal were assessed as well as the best species were determined for Bolzano city with aim to quantify the benefits of urban trees in Bolzano, to compare these results with other similar studies in order to assess the consistency and effectiveness of the methods, to increase the awareness on the important role GIs play in urban systems for policy-makers, and to take into account the recommended species for planting to enhance ecosystem services.

4.1. Analysis and implications from results

In addition to improving human health, ecosystem services from green infrastructure can have direct benefits on the environment (Konijnendijk et al., 2013; O'Brien et al., 2013). For Bolzano, expanding urban forestry could further enhance its carbon sequestration capacity, supporting broader climate action goals (Hayes, 2023). These data underscore the crucial role of urban forests in mitigating climate change through carbon sequestration. The variation in numbers across cities can be attributed to differences in tree density, species, and local environmental policies.

4.1.1. Carbon storage and sequestration

i-Tree Eco calculates urban forest carbon storage (CS) and gross carbon sequestration (GCS) using a tree growth model and biomass equation. These calculations are based on factors such as tree species, diameter at breast height (DBH), crown coverage, and tree health (Ma et al., 2021).

While carbon sequestration often correlates with the quantity of trees, it is important to note that other factors also play a significant role. The study (Y. Yang et al., 2023) found that different types of green spaces exhibit varying capacities for carbon sequestration: public parks had the highest net carbon sequestration efficiency in comparison with incorporating green space, square

Table 7
Comparative table of carbon removal in different cities with i-Tree Method.

Study area	Number of Trees	C storage (t)	Gross C sequestration (t)	C sequestration per tree (t)
Bolzano	11,948	5160.59	73.02	0.0061
Beijing [1]	Na	1,114,298.23	81,568.3	Na
Luohe[2]	1,006,251	54,329	4973	0.0049
Krakow [3]	582	441.59	8.733	0.0150
Zhengzhou[4]	2083	75.7	14.66	0.0070
Bandung [5]	1607	381	25.17	0.0660

Na = not available.
[1] (Ma et al., 2021).
[2] (Song et al., 2020).
[3] (Siedlarczyk et al., 2019).
[4] (Y. Yang et al., 2023).
[5] (Afrianti et al., 2024).

green space and attached green space. However, understanding the abundance of specific tree species is crucial as certain varieties may possess greater capacity for carbon storage and sequestration (Lugo-Pérez et al., 2023). For example, (Piyaphongkul et al., 2011) in their study conducted a comparative study to assess the carbon sequestration capacities of different tree species in urban environments. By comparing the growth rates and carbon sequestration abilities of Oak *(Quercus robur)* and Maple (*Acer platanoides)* trees over a 10-year period, the researchers found that Oak trees sequestered significantly more carbon than Maple trees, despite similar growth rates. This research highlights the importance of selecting tree species with high carbon sequestration potential for urban forestry and reforestation initiatives, offering valuable insights for climate mitigation strategies in urban areas.

The study of (Pace et al., 2018) found that biomass growth, and thus carbon sequestration, depends solely on the size of the trees and their competition state, not on species- or genus-specific traits. Also, they simulated a scenario with a dominant species, where carbon sequestration increased by 5.7 %, reaching 226 t. This indicates that under certain conditions, more trees grow into larger size classes, enhancing carbon sequestration. Transmission coefficients, which affect light transmission through the canopy, play a role. For instance, maples allow less light to pass through, reducing competition and promoting the growth of larger trees, thereby increasing carbon sequestration. This means that regardless of the species, larger trees and those less affected by competition sequester more carbon. In our work, the number is really low, 73.02 t/yr, due to the small size of the trees and or facing higher competition, limiting their growth and carbon storage capacity. However, according to other studies, carbon sequestration per tree was similar in Beijing, Luohe, Krakow, Zhengzhou, and Bandung Table 7. So, to increase total sequeatration, we suggest to focus on strategic planting, reducing competition (e.g., through thinning) and promoting the growth of larger trees, regardless of species.

4.1.2. Avoided runoff

Urban trees play a crucial role in stormwater mitigation by intercepting precipitation, promoting infiltration in their root zones, and absorbing soil water via transpiration, which collectively helps reduce stormwater volumes (Dowtin et al., 2023). While all components of a tree's physical structure—such as leaves, branches, and bark—are essential in capturing precipitation, this analysis, as well as that of (Ross et al., 2020) only accounted for the amount of water retained by the leaves.

Our results in stormwater management indicate that the urban trees in Bolzano were able to intercept 39,675.90 m^3/year of precipitation and mitigate 8019.97 m^3/year of runoff. The most effective species in terms of runoff reduction were Saucer magnolia and Sycamore spp., likely due to their large leaf areas, which were 28.30 ha and 27.43 ha, respectively. In contrast, the most abundant species in Bolzano, Norway maple, has five times more individuals than Saucer magnolia, yet its smaller leaf area likely explains its lower capacity for runoff reduction. This suggests that the environmental benefits of urban trees are more strongly correlated with leaf surface area than with species abundance in the urban forest. This finding is also supported by (Ross et al., 2020), who highlight the importance of leaf area in stormwater mitigation.

In addition to leaf area, the physical characteristics of the foliage can influence the amount, spatial distribution, and temporal variation of rainfall interception. Factors such as leaf angle, hydrophobicity, leaf shape, structure, and surface roughness can all impact how much rain is intercepted, leading to significant differences in rainfall interception across urban tree canopies (UTC) (Dowtin et al., 2023).

In Table 8, we compare the results from our study in Bolzano with the study conducted at the Oak Ridge Reservation (ORR), USA (Ross et al., 2020), focusing on the avoided runoff per tree for the top-performing species. While we recognize that this table is orientative and that LAI is an important factor to consider, our focus here is on species-specific characteristics. Based on this limited analysis, we found that *Saucer magnolia* has the greatest influence on stormwater mitigation, with the highest avoided runoff per tree,

Table 8
Comparative table on stormwater mitigation.

Bolzano					
Tree Species	Number of Trees	Avoided Runoff (m^3/year)	Water Intercepted (m^3/year)	Avoided Runoff per Tree (m^3/tree/year)	Water Intercepted per Tree (m^3/tree/year)
Saucer magnolia	108	742.22	3671.87	6.87	33.99
Sycamore spp	346	719.22	3558.09	2.08	10.28
American basswood	168	321.35	1589.77	1.91	9.46
ORR in Anderson and Roane County Tennessee, USA (Ross et al., 2020)					
Pin oak	72	114.81	522.43	1.59	7.25
Eastern redcedar	67	95.07	432.6	1.42	6.45
American sycamore	45	90.47	411.69	2.01	9.15

outperforming *Sycamore* spp., *American basswood, Pin oak, Eastern redcedar, and American sycamore.* Given the limited scope of this analysis, further studies with more data points and the inclusion of variables such as LAI would be necessary for a more comprehensive comparison.

4.1.3. Air pollution removal

The results showed that total air pollution removal was 2908 kg with ozone the most 1717.98 kg and $PM_{2.5}$ the least −3.32 kg. It is common for ozone removal in cities to be relatively high due to the relatively high deposition velocities and local ozone concentrations (Selmi et al., 2016). Differences in removal rates were due to differences in the average amount of healthy leaf area per tree (Russo et al., 2016a, 2016b) and due to the combination of relatively high pollutant concentrations and the trees' effective removal rates. A greater tree cover generally results in a greater reduction of pollution. Additionally, as both removal rates and population density increase, so does the overall value. Trees reduce air temperatures, which can lead to reduced emissions from various anthropogenic sources (Nowak et al., 2014a, 2014b).

Studies (Selmi et al., 2016) have demonstrated that urban trees play a role in mitigating air pollution, but they are just one of many potential solutions. Reducing emissions at the source is essential for preventing pollution, and trees should not be viewed as an alternative to emission reduction but rather as a complementary measure. Although not explored in this study, trees can also contribute to lowering pollutant emissions by reducing air temperatures and decreasing building energy consumption. However, trees can also produce particles (e.g., pollen), which limits pollutant dispersion and increases local concentrations (e.g., near highways). Urban trees in the U.S. have been estimated to remove about 711,000,000 kg of air pollutants annually across all urban areas (Nowak et al., 2006). While our data are for a specific location and thus much smaller in scale, the per hectare removal rates could be compared for more granularity.

Seasonal pollution removal is shown in Fig. 11. We observed that for almost all air pollutants (NO_2, O_3, PM_{10}, $PM_{2.5}$ and SO_2), the

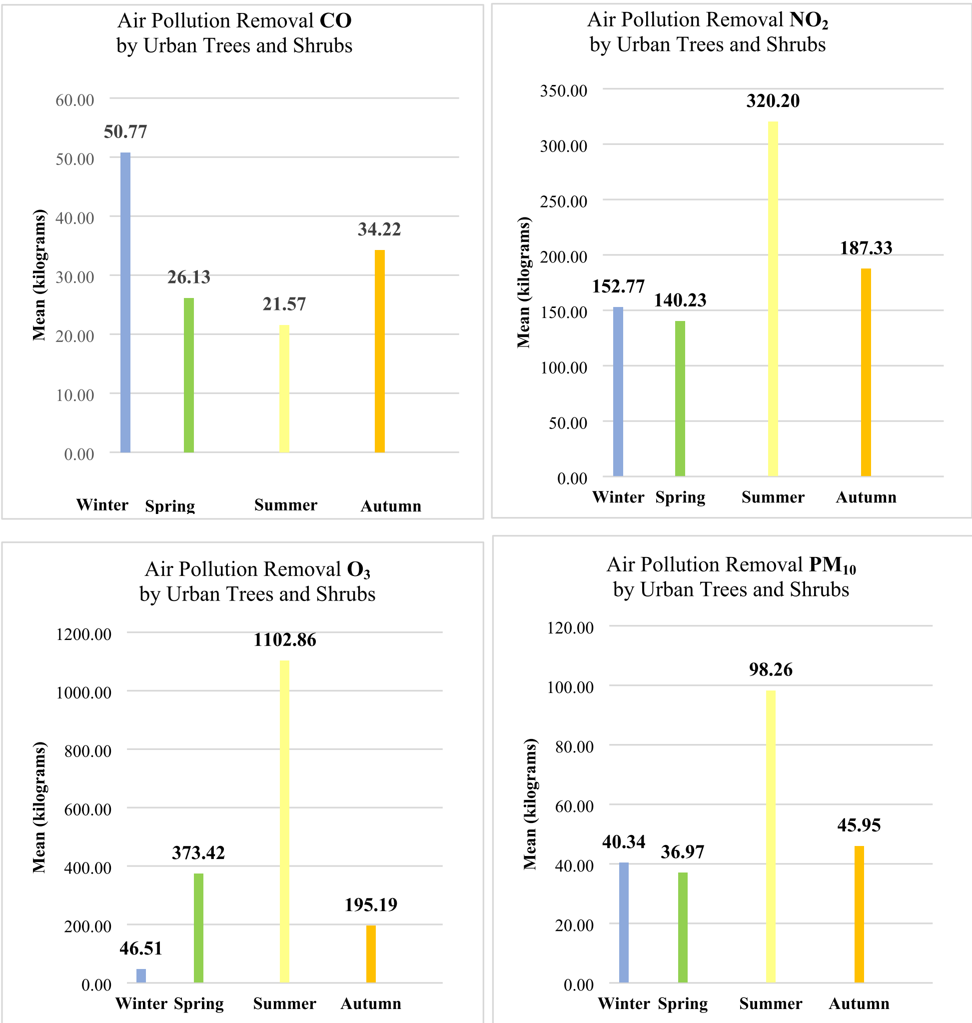

Fig. 11. Annual pollution removed by season.

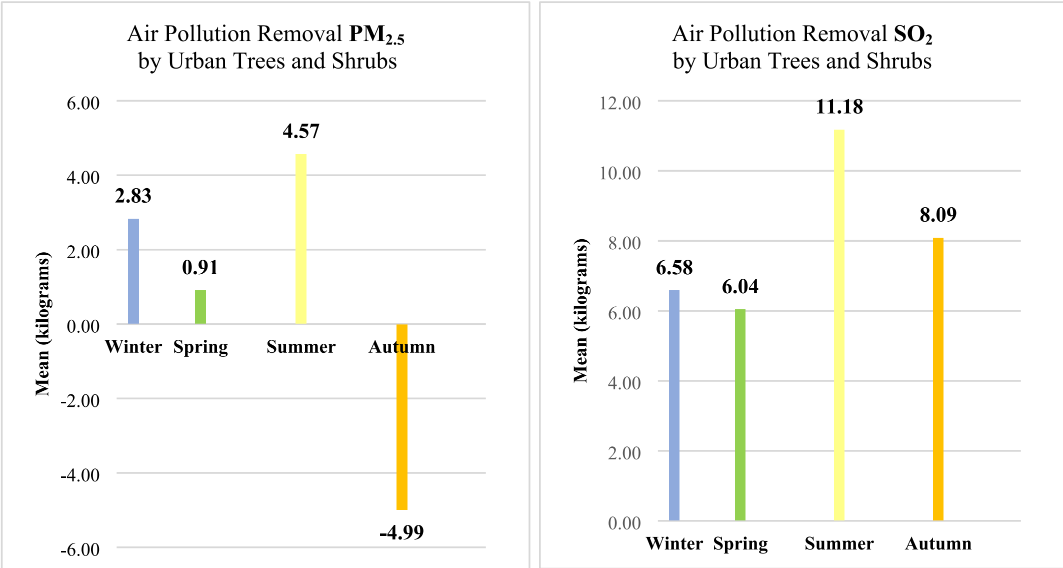

Fig. 11. (*continued*).

highest removal was during summer, except for CO, which was during winter. The difference behavior of CO removal compared to other gaseous pollutants is related leaf area, possibly because it is not dependent on photosynthesis and transpiration. Unlike pollutants such as O_3 and NO_2, which are taken up by stomata and influenced by environmental conditions like drought stress, CO removal primarily occurs in the soil rather than through plant leaves. Therefore, its deposition is not affected by the physiological processes of the plants, making its removal process distinct from other pollutants (Pace et al., 2018).

Additionally, according to (Hirabayashi and Kroll, 2017) CO levels are sensitive to cold season temperature inversions which trap the gas beneath a layer of warm air, leading to higher concentrations during cold seasons.

Satoshi Hirabayashi and Alexis Ellis (personal communication, April 2024) explained the negative result of $PM_{2.5}$ in autumn which is also supported by the findings of (Paudel and States, 2023). $PM_{2.5}$ deposited on leaves accumulate with time until they are washed off by rainfall. The accumulated particles are resuspended into the air by wind, which results in increased $PM_{2.5}$ concentrations on an hourly basis. Depending on the combination of factors such as wind speed, timing and amount of rainfall, and the accumulated mass of PM2.5, the seasonal and/or annual removal of pollutants may sometimes be negative. The effect of the resuspension due to the lack of precipitation is higher, thus reducing the net $PM_{2.5}$ removal.

Another interesting observation was made by (J. Yang et al., 2015). Among the ten most frequently occurring tree species, only the London plane (*Platanus acerifolia (Aiton) Wild.)*, silver maple (*Acer saccharinum L.*), and honey locust (*Gleditsia triacanthos L.*) demonstrated $PM_{2.5}$ removal rates above average. However, there exists considerable potential for enhancing $PM_{2.5}$ removal from urban air by leveraging species with high efficiency in this regard, particularly conifer species. Despite their low representation in our study—silver maple at 0.73 % and honey locust at 0.43 %—incorporating such species in urban forestry initiatives holds promise.

The ability of these trees to effectively filter $PM_{2.5}$ is particularly pertinent given its capacity to deeply infiltrate the respiratory system, its association with a spectrum of severe health complications, and its disproportionate impact on vulnerable demographics. Hence, prioritizing the planting of species with robust $PM_{2.5}$ removal capabilities emerges as a prudent strategy. This underscores the imperative of diligent monitoring and concerted efforts to mitigate $PM_{2.5}$ levels in urban environments to safeguard public health (World Health Organization. Regional Office for Europe, 2021).

A recent study in Bolzano from 2016 (Russo et al., 2016a, 2016b) showed that toal air pollutant removal was 2.42 metric tons per yer (t/yr), where O_3 was removed the most 1.2 t/yr and CO (0.03 t/yr) removed the least. It was also noted that the greatest air pollution removal was in parks t due to the greater number of trees. Although in that research only 4 air pollutants were assessed (CO, NO_2, O_3, PM_{10}), whereas we assessed 6 pollutants, the difference in air pollution removal is not significant: our research found 2.908 tons of air pollution removed compared to 2.42 tons in their research.

According to the research (Selmi et al., 2016) in Strasbourg city, the role of urban trees in reducing air pollution is for the first time being examined in France. Comparison of removal rates with emissions rates in Strasbourg city showed that trees modestly remove air pollution. The amount of air pollution removed in Strasbourg is 88 t/yr due to the high level of urban green spaces. Overall public green spaces occupy about 2171 ha (about 27.80 % of the city area) with 588,000 trees estimated. It is one of the top Ten French Cities in green space surfaces according to the national union of landscape companies (Selmi et al., 2016).

Recent research in Kaunas city with the 284,305 trees and 64 % of green area have removed approximately 25,239 t of (NO_2, PM_{10}, CO_2) with 2084 tons of NO_2, 217 tons of $PM_{10,}$ and 22,938 tons of CO_2 (Araminienė et al., 2023).

Urban trees help to mitigate air pollution, but they are one of many potential solutions to this problem (Hassan and Ahmed, 2021).

Table 9
Results Summary for Bolzano (annual).

Assessed ecosystem service	Total biophysical value	Total economic value	Best species
Air pollution removal	3 t	125,955.4 €	*Saucer magnolia and Sycamore spp*
Carbon sequestration	73.02 t	5300 €	*Deodar cedar and Norway maple*
Carbon storage	5160.59 t	375,000 €	*Deodar cedar and Sycamore spp*
Avoided runoff	8019.97 m^3	18,932.27 €.	*Saucer magnolia and Sycamore spp*
Oxygen production	194.80 t	*ND*	*Deodar cedar and Norway maple*

4.2. Summary

Based on the i-Tree Eco analysis, we have drawn conclusions for Bolzano and other European cities with similar climates regarding total biophysical and economic values, and the top-performing tree species in Bolzano (Table 9).

This analysis highlights the significant contributions of specific tree species to various ecosystem services in Bolzano. Among tree species, Saucer magnolia and Sycamore trees are the most effective at removing air pollution, while Deodar cedar and Norway maple are the most efficient at storing carbon and producing oxygen. *Deodar cedar* and *Sycamore species* also showed the highest carbon storage capacity. In terms of avoided runoff, Saucer magnolia and *Sycamore species* again proved to be the most beneficial. These findings can guide urban forestry planning and management in Bolzano and similar European cities.

5. Conclusions

In this research, we used quantitative method with the application of i-Tree Eco to show the importance of trees in urban area. The results of this study showed that Green Infrastructure in Bolzano generated a large variety of ecosystem services with significant biophysical and monetary values which can be useful addition for urban planning not only for Bolzano but also for for a city with similar climate of Bolzano.

Based on our research, we concluded that in Bolzano, certain tree species provide significant ecosystem services, which are crucial for stakeholders to consider and enhance human well-being. The most important species that absorb more pollutants and that prevents runoff are *Saucer magnolia* and *Sycamore* spp. *Deodar cedar* and *Norway maple* excelled in carbon sequestration and oxygen production. The highest carbon storage capacity was demonstrated by *Deodar cedar* and *Sycamore trees.* In the future, urban planners or managers could use the performance of different types of urban green spaces in providing various ecosystem services to set specific planning goals. By considering factors such as species selection, maintenance needs, and social equity, urban planners can leverage the ecosystem services provided by trees to create healthier, more resilient, and more sustainable cities. This approach maximizes environmental benefits and improves the quality of life for residents, aligning with Sustainable Development Goal 11: Sustainable Cities and Communities, as well as Sustainable Development Goal 3: Good Health and Well-Being, thereby enhancing overall human well-being.

The concept of GI in cities is becoming increasingly important for the development of urban policies aimed at improving the quality of life while mitigating the adverse effects of climate change. The results of this study will increase the awareness on the important role GIs play in urban systems to improve human well-being, also informing policy-makers in charge of developing conservation and sustainability strategies.

In conclusion, this study enhances the understanding of Green Infrastructure in Bolzano by evaluating its benefits in biophysical and monetary terms and identifying optimal species. The findings provide a foundation for developing an online tool to support GI planning and urban ecosystem service assessments, both in Bolzano and in cities with similar climates across Europe.

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CRediT authorship contribution statement

Milena V. Sokolova: Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Brian D. Fath:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Investigation, Formal analysis, Conceptualization. **Elvira Buonocore:** Writing – review & editing, Visualization, Validation, Supervision, Investigation, Conceptualization. **Pier Paolo Franzese:** Writing – review & editing, Visualization, Supervision, Resources, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Appendix

Table 10
Place of native range.

City district	Africa	Africa & Asia	Asia	Asia & Oceania	Europe	Europe & Africa	Europe & Asia	Europe & Asia +	North America	North America +	North & South America +	Oceania	South America	Unknown
Centro Piani Rencio	1,30	0,10	17,50		22,60		24,30	13,00	13,40	7,60	0,30			0,10
Oltrisarco Asiago	1,60		19,00		7,70		26,80	8,50	30,10	6,00	0,20			0,10
Europa Novacella	2,10		27,10	0,10	9,10	0,10	29,00	5,00	22,00	5,10	0,10	0,10		0,20
Don Bosco	1,40		22,70	0,40	9,70		27,80	5,80	24,30	6,60	0,60			0,70
Gries S.Quirino	1,30		19,00	0,50	12,50	0,20	36,20	6,10	21,40	2,40	0,20		0,00	0,20

The '+' sign indicates that the species is native to another continent other than the continents listed in the grouping. For example, Europe & Asia + would indicate that the species is native to Europe, Asia, and one other continent. Oceania, including: Australasia, Melanesia, Micronesia and Polynesia.

Appendix B. Appendix

Table 11
Benefit prices (UU.S. Forest Service, N. R. S, 2023).

Electricity € (EUR)/kWh	0.31
Fuels € (EUR)/Therm	1.77
Carbon € (EUR)/metric ton	80.00
Avoided Runoff € (EUR)/m^3	2.361

Appendix C. Appendix

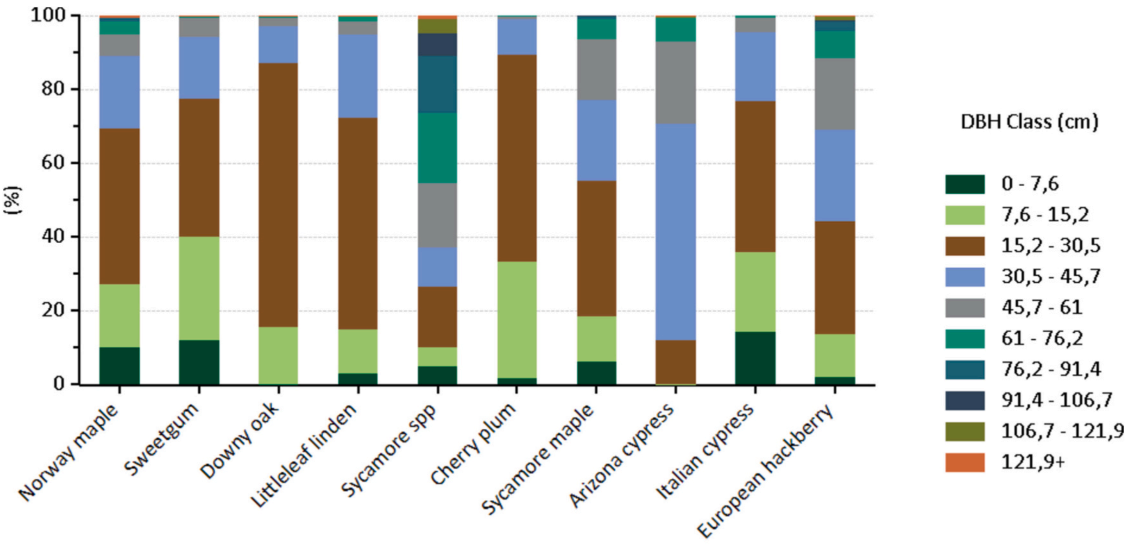

Fig. 12. Species distribution by DBH class (U.S. Forest Service, N. R. S, 2023).

Appendix D. Appendix

The most dominant species in terms of leaf area are *Saucer magnolia*, *Sycamore spp*, and *American basswood*. The 10 species with the greatest importance values are listed in Table 12. The importance values (IV) are calculated by summing population and leaf area percentages. These trees are currently dominant in the urban forest structure, but their high importance values do not necessarily imply they should be encouraged in the future.

Table 12
Most important species in Ecosystem services assessment of Bolzano (U.S. Forest Service, N. R. S, 2023).

Species name	Percent population	Percent leaf area	IV
Sycamore spp	2.9	9.0	11.9
Saucer magnolia	0.9	9.3	10.2
Norway maple	4.6	3.0	7.6
Sweetgum	4.0	2.3	6.3
Sycamore maple	2.8	3.2	6.0
Deodar cedar	2.1	3.7	5.9
Littleleaf linden	3.1	2.5	5.6
American basswood	1.4	4.0	5.4
Incense cedar	2.0	3.3	5.3
European hackberry	2.3	2.9	5.3

Data availability

The authors do not have permission to share data.

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