smart cities

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Engaging Young People in the Development of Innovative Nature-Inspired Technologies for Carbon Sequestration in Cities: Case Studies from Portugal

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Abstract: Currently, cities are the most vulnerable places on the planet to the effects of global change, both anthropogenic and climate-related, and this is not compatible with harmony and well-being regarding the economy, nature, and future generations. Young people have a unique potential to catalyze the transformative sustainable change that the planet needs now, as they are the first generation to grow up with tangible impacts of climate change. We tested a new strategy to empower young people to foster carbon neutrality in cities by engaging them in ecosystem services quantification and technological innovation to increase CO_2 sequestration in two Portuguese cities. The species with best performance for carbon sequestration were *M. exelsa* in Porto and *O. europea* in Loulé, and for air pollutant removal and hydrological regulation were *P. hispanica* in Porto and *P. pinea* in Loulé. Through the innovative advanced summer program SLI, a nature-based learning experience, young people developed two new concepts of technological solutions to accelerate city decarbonization by designing a hedge for air pollution hotspots and a biodevice to be placed at bus stops using autochthonous shrubs and mosses. Initiatives like SLI contribute to a greater awareness among young people about the drivers that brought us to the current climate emergency, motivating them towards more balanced lifestyles and creating innovative nature-based solutions towards a smart and sustainable city.

Keywords: youth and sustainability; climate change; carbon neutrality; urban ecosystem services; sustainable solutions for smart cities

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1. Introduction

The world's population reached 8.045 billion in 2023 [1], and projections suggest that it could grow to around 8.5 billion in 2030, 9.7 billion in 2050, and 10.4 billion in 2100, in part due to population growth caused by declining levels of mortality, as reflected in increased levels of life expectancy at birth [2]. Understanding population trends and anticipating demographic change are crucial for national development planning and implementing the 2030 Agenda for Sustainable Development.

The current consumption patterns and demand for natural resources for all human activities are beyond what is sustainable, causing serious damage to the Earth and human health [3–5], related to the increase in the atmospheric concentration of different greenhouse gases, including CO_2. There are three major fluxes that determine the atmospheric concentration of CO_2: biogenic land ecosystem fluxes, ocean fluxes, and human-induced emissions [6]. Carbon fluxes in land ecosystems have high variability and need to be better analyzed. Greenhouse gas emissions induced by human activities have unequivocally caused global warming, with global surface temperature reaching 1.1 °C above 1850–1900 levels in 2011–2020, changes in precipitation patterns, and ocean acidification that are leading to serious biodiversity loss. Despite this, greenhouse gas emissions continue to increase, mainly due to four major anthropogenic sources: fossil fuels (extraction and burning of coal, oil, and gas), land use, land use change, and forestry (deforestation, soil disturbances, etc.) [7,8]. On average, currently, just about a quarter of the global human-induced CO_2 emissions are sequestered and stored, mainly in forest soils and aboveground biomass [9].

Since 2007, more than half of the world's population has lived in cities, and by 2050, it is projected that 68% of people will live in urban areas. However, urban settings are a relatively new phenomenon in human history, and this transition has transformed the way we live, work, travel, and build networks [10]. Cities, centering people, infrastructure, and services, are particularly vulnerable, and represent 80% of energy consumption and 75% of total carbon emissions [11].

The burning of fossil fuels that support the transport of people and goods and the production of non-renewable energy is responsible for emissions that linger in the atmosphere for hundreds of years [7,8] that are considered the main drivers of both man-made climate change and urban air pollution [12]. In Europe, released pollutants such as fine particles, nitrogen oxides, sulfur dioxides, and others remain a major challenge, being a major cause of premature death and disease (mainly respiratory and cardiovascular) and the single largest environmental health risk. Recent studies relate the influence of climate change on air pollution in urbanized regions [5,8], showing a clear pattern for the future across Europe with an increase in PM_{10}, $PM_{2.5}$, and NO_2 concentrations, mainly in the warm season [13,14]. The consequences of climate change (e.g., heat islands, water scarcity, and rising sea levels) and air pollution are not compatible with the harmony and well-being that a sustainable city must provide concerning the economy, nature, and people from current and future generations [15,16], and are strongly challenging for scientific research and technological innovation. Were the new World Health Organization (WHO) air quality guidelines met across Europe, then this would have delivered a 72% drop in premature deaths across the EU compared with 2005 levels [17]. For every 10 g/m^3 of $PM_{2.5}$ humans are exposed to, life expectancy falls by 0.98 years; lowering the concentration of PM to meet guidelines set by the WHO can raise average global life expectancy by roughly two years [18]. Cities also play a significant role in freshwater management, as they impact both water quantity and quality, and future urban design needs to integrate traditional water services developed in recent decades with the ecosystem services provided by nature in cities [19,20].

In 2021, after the COVID-19 crisis, which offered only a temporary reduction in global carbon emissions [21], the EU Climate Law established a framework for a gradual and irreversible reduction in greenhouse gas emissions by anthropogenic sources and the enhancement of removals by sinks regulated in EU law. To overcome these challenges, the European Green Deal was designed, aiming to transform the EU into a modern, resource-efficient, and competitive economy. Beyond the reduction of the EU's greenhouse gas emissions by at least 55% by 2030, the Green Deal aims to achieve carbon neutrality by 2050 by increasing and strengthening carbon sinks as a tool to mitigate and adapt to climate change, thereby preserving biodiversity [22].

Nature-based solutions (NBSs) aim to help societies address a variety of environmental, social, and economic challenges in sustainable ways. During the last few decades, different studies have demonstrated how nature works and how it can benefit all people through different ecosystem services, namely, by improving the water and carbon cycles in cities [15,23]. Besides their contribution to carbon (CO_2) sequestration through photosynthesis ($6\ CO_2 + 6\ H_2O \rightarrow 6\ C_6H_{12}O_6 + 6\ O_2$), plants can also improve urban air quality by removing air pollutants, absorbing them through their stomata or simply retaining them on the surface of their tissues [19,24,25]. NBSs require new processes for design and implementation that are by their very nature more inclusive and that can provide outcomes that are transformative for nature, people, and places. In line with the EU [26], NBSs are a means through which it is possible to generate sustainable communities, with the potential to offer a transformative approach to meeting sustainability challenges. Cities' aesthetics will be improved by the integration of green areas in urban spaces, which also contribute to increasing biodiversity, tackling heat waves, and tackling climate change effects. The promotion of sustainable lifestyles requires increasing citizens' awareness of their contribution to the decarbonization of the cities where they live. Public attention to the environment is an important form of environmental protection [27]. However, previous studies report that public awareness of air pollution mainly depends on education and income [28]. Given that health problems are the most important consequence of low air quality, public opinion should be a driver of air pollution reduction and government policy.

A previous study reported by Zhang et al. [29] found public opinion pressure on the government has an ameliorating effect on air quality, but it can still be short-lived. Young people have a unique potential to catalyze the transformative sustainable change that the planet needs now, as they are the first generation to grow up with tangible impacts of global warming, such as heatwaves, floods, and droughts, for which they were not responsible [30]. In general, Generation Z (those born between 1995 and 2009) is concerned about environmental protection actions and pollution's negative effects, preferring a healthier environment, often choosing sustainable principles, and being keener to adopt green products, even if this comes at higher monetary costs [31]. Thus, the design of innovative solutions for adapting to climate change must involve young people, as they will determine the success of new products and services and consequently the path towards carbon neutrality. To accelerate cities' decarbonization, it is essential to reduce greenhouse gas emissions to a minimum and increase carbon sequestration by taking advantage of the partnership between nature's services and technology, and, to a certain extent, meeting young people's requirements. Therefore, new biodevices for carbon sequestration must be developed with the active intervention of young people.

Aware of Generation Z's importance in designing solutions for carbon neutrality, the Centre of Engineering and Product Development (CEiiA), a non-profit private organization, organizes the Sustainable Living Innovators (SLI) program for four weeks in the summer. The SLI is an advanced program in which a group of 20 high school and university students explores concepts of innovative products and services that promote the planet's sustainability. The 2021 and 2022 SLI editions aimed to empower Generation Z, contributing to a transformative and inspirational movement that will induce new ways of living together and closest to nature in urban spaces for the transition towards carbon-neutral, inclusive, and beautiful cities, according to the New European Bauhaus initiative. During the SLI program, youngsters were trained on sustainability drivers and challenged by senior researchers, engineers, and designers to connect technology and nature to devices for urban air cleaning.

The International Union for Conservation of Nature [32] defines NBSs as actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing well-being and biodiversity benefits. Whereas nature-based learning is in general learning through exposure to nature in an urban, rural, or wilderness context [33], nature-based solution learning looks directly into the answers for mitigating and adapting to climate change impacts [34]. Improving students' understanding of climate change has become critical, as a UNESCO online survey of 17,471 young people from 166 countries in 2022 found 70% of them were dissatisfied and doubted the quality of climate change education, which they demanded be improved [35]. Robust evidence shows that experiences with nature promote learning, nature connection, and awareness [36], and the challenge increases in wealthier countries as their youth tend to feel less connected to nature than those from less wealthy countries [37]. Moreover, it has been emphasized recently [38] that it is urgent and essential to investigate carbon sequestration benefits on a local scale.

As far as our knowledge is concerned, there are no studies available in the literature reporting the engagement of young people in the development of innovative nature-inspired technologies for carbon sequestration, particularly in Portuguese cities. Thus, the main objective of this work was to present a new approach to how to empower young people to foster carbon neutrality in cities by engaging them in ecosystem services quantification and technological innovation to increase CO_2 sequestration, using two Portuguese cities as case studies and thus contributing to the idea of smart cities.

During SLI at CEiiA, both case studies promoted the direct contact between young people and nature within cities. To quantify the services that nature provides to the community, *in situ* measurements of selected trees that interact directly with urban pollution were performed and integrated with pollution and meteorological data collected in the same locations by the Portuguese Environment Agency (APA) and Portuguese Institute for Sea and Atmosphere (IPMA). Then, a peer-reviewed technological tool for the calculations was used. Integrating the results for carbon sequestration by urban trees with both cities' features allowed the young people to discuss and realize the need to develop new technological solutions, motivating them to work on concepts for urban biodevices that can improve the effect of nature in cities.

Thus, advanced summer program of SLI was an innovative nature-based learning experience, in which young people were challenged to develop new technological solutions to accelerate cities' decarbonization by configuring cyber-physical biodevices.

2. Materials and Methods

The pedagogical strategy used in SLI comprised three consecutive stages: motivation for the challenge; quantification of the role of nature, using two case studies; and empowerment of young people for nature-based technological innovation.

2.1. Sustainable Living Innovators—Motivation

In the preferably technological environment of CEiiA, the youngsters attended an innovative program called SLI, in which they explored new approaches for (bio)device concepts inspired by nature, for carbon sequestration and air pollutant removal from the urban atmosphere. The candidates for the SLI program were selected by a jury of researchers and engineers from CEiiA among students from different areas of knowledge in the domains of engineering, life and health sciences, architecture, and design, and coming from different regions of the country to ensure equal opportunities and gender equality. The selection criteria for the 20 students were school performance and soft skills (50%) and motivation for planet sustainability issues expressed in a submitted letter and during the final interview (50%). The SLI 2021 and 2022 editions took place between mid-July and mid-August and were designed with an innovative collaborative pedagogical approach between students ("innovators") and researchers/engineers ("activators"), focusing on real-world case analysis to stimulate the younger students' curiosity for the principles of (un)sustainability. Collaborators from several public and private entities, including Portuguese universities, municipalities, and private companies, were involved as activators to inspire and equip these young people with different tools for valuing knowledge and technology in new products and innovative services designed from a sustainability standpoint. During both SLI editions, interaction and leadership skills that allow young people to assert their values and mobilize others around the realization of their ideas were promoted. The different background profiles of the activators ensured several areas of knowledge relevant to preparing a new generation of leaders who value innovation to foster the quality of life and the sustainability of the planet.

During the first two weeks of SLI, theoretical and practical sessions were addressed mainly to inspire and motivate young people using an international perspective focused on the challenges that cities are facing. We included modules on climate change, the UN Sustainable Development Goals, ecosystem services, nature-based solutions, the green economy, new business models for sustainability, carbon fluxes and carbon neutrality in cities, and carbon sequestration by plant biomass.

After considering the global perspective, young people were encouraged to take action locally in their cities through two case studies.

2.2. The Role of Nature in Carbon Neutrality in Cities

As case studies, two urban areas were selected: Porto, which is the second-largest city in Portugal, and Loulé Municipality in the Algarve region in the south of the country (Figure 1). Characterization of each urban area was done, considering the main socioeconomic aspects and environmental constraints (Table 1). In Porto, the Parque da Cidade (41.169167 N; −8.680323 W), built in 1993 and extended to its current dimensions in 2002, was considered the largest urban park in the country, with an area of 826,670 m^2, including 543,343 m^2 of cultivated areas, 35,227 m^2 of lakes, and 11 km of pedestrian paths, plus public buildings and parking. In Loulé, the Jardim das Comunidades—Almancil (37.084943 N; −8.033542 W) was built in 2003 and is one of the largest urban green spaces in the Algarve region, with an area of 12,180 m^2 including cultivated areas, pedestrian paths, and children's and seniors' play areas, plus a lake of 1200 m^2.

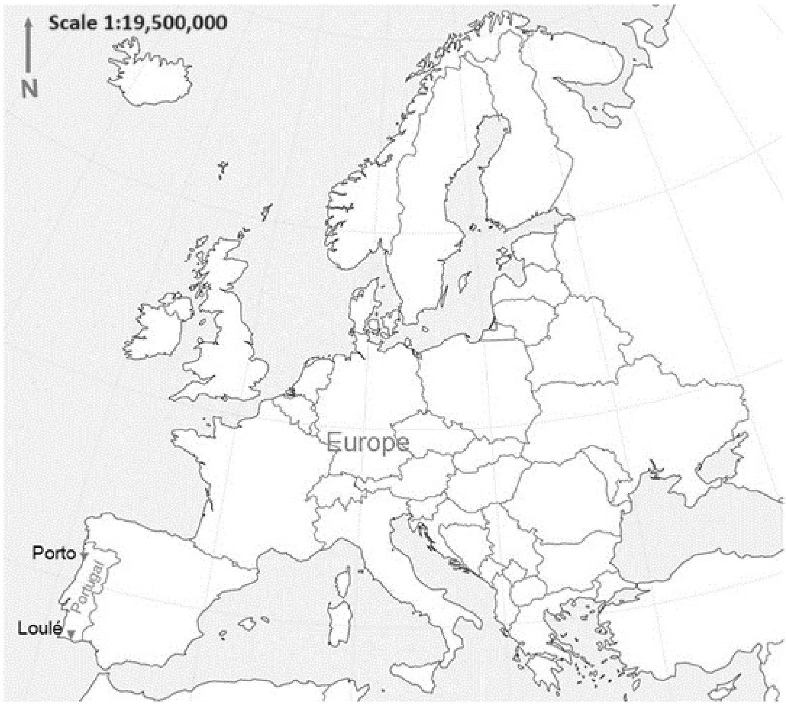

Figure 1. Location of cities selected as case studies.

2.2.1. In Situ Measurements

To raise young people's awareness of the services provided by autochthonous trees, during the practical sessions of SLI 2022, we visited green spaces to collect real data. In Parque da Cidade, Porto, we selected the autochthonous tree species *Cupressus lusitanica*, *Platanus hispanica*, *Metrosideros excelsa*, and *Pinus pinea*, and in Jardim das Comunidades, Loulé, we chose *Ceratonia siliqua*, *Olea europaea*, and *Pinus pinea*. For each species, we identified five representative individuals and measured their total height, crown base height, crown width, diameter at breast height, and percentage crown missing. We considered in situ recent pollution data, collected in the vicinity of both green spaces by the APA. Both green spaces are surrounded by main roads, and the studied trees stand in areas directly influenced by emissions from road traffic. The meteorological data for each city were collected by local weather stations from the IPMA.

2.2.2. In-Process Measurements

To quantify the ecosystem services provided by each urban tree species, we used an application of the peer-reviewed software i-Tree Eco v6 developed by the USDA Forest Service Northern Research Station (available at itreetools.org). Ecosystem services included carbon sequestration and storage, oxygen production, air pollutant removal, and hydrology effects (potential evapotranspiration, transpiration, evaporation, water intercepted, and runoff avoided). The quantification of air pollutants removed per year by trees included ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), $PM_{2.5}$, PM_{10}, and sulfur dioxide (SO_2).

To assess whether there were significant differences ($p < 0.05$) in the results for ecosystem services (CO_2 sequestration, O_2 production, and air pollutant removal) provided by different tree species, a one-way ANOVA test was performed for a significance level of 0.05 using SPSS 27 [39]. After this, Duncan's test was used to check if there was any relationship between the trees and the detected differences. In the case of *Pinus pinea*, Student's *t*-test ($p < 0.05$) was performed to evaluate the differences between the means obtained for both cities.

In this context, the relevance of the ecosystem services provided by the tree's species was analyzed and discussed, considering the features of both urban areas presented in Table 1.

Table 1. An overview of the urban areas selected as case studies [40,41].

	Porto City	Loulé Municipality
Area (ha)	4035.39	76,367
Population (inhabitants)	231,800	72,332
Density (people/km^2)	575	10
Köppen–Geiger climate classification	Mediterranean Csb	Mediterranean Csa
Main economic activities	From the tertiary sector: health, tourism, commerce, and business services linked to ICT.	From the primary sector: agriculture, fisheries, and salt production. From the tertiary sector: tourism.
Carbon emissions per capita (t/year)	2.04	1.59
Green area *per capita* (m^2)	14.2	9675
Main environmental constraints	Air pollution due to road traffic, heat waves, urban flooding due to extreme precipitation events, an increase in Douro River flow, and strong sea waves; a rise in mean sea level, storms or tornadoes, landslide [42]	Decrease in mean annual precipitation and water scarcity, extreme precipitation events with urban flooding, heat waves; wildfires, rise in mean sea level and coastal erosion, and biodiversity loss [43]

2.3. Sustainable Living Innovators—Empowerment

To face the challenge of combining technology, nature, and youth creativity to accelerate carbon neutrality, several researchers and senior engineers addressed key issues to empower the young during the third and fourth weeks of SLI. Through different theoretical, expository, and practical sessions, including in a laboratory context at CEiiA, the activators explored modules on design thinking, teamwork methodologies, software, electronics, connectivity, cyber-physical systems, materials with a low carbon footprint, the product life cycle, plant physiology and biotechnology, and business plan development.

3. Results and Discussion

3.1. Ecosystem Service Quantification

It is already known e.g., [15,44–49] that different tree species supply ecosystem services with different efficiency and that within each species, the size and condition of the sampled trees are relevant factors, namely, for carbon sequestration and storage. This study held in the summer period in two Portuguese cities confirmed some significant differences ($p < 0.05$) in the ability of the tree species to sequester CO_2 and produce O_2 (Table 2).

Table 2. Comparison of ecosystem services provided by trees in the public green spaces considered in both cities.

Parque da Cidade, Porto		***Cupressus lusitanica***	***Platanus hispanica***	***Metrosideros excelsa***	***Pinus pinea***
Leaf area per tree (m^2), min–max		68.5–867	438–1240	164–946	310–449
C storage per tree (kg), mean ± SD		2656 ± 2143	2461 ± 2808	4563 ± 3163	605 ± 286
Min-Max		213–6045	673–7412	436–7500	247–950
CO_2 sequest. per tree (kg/year), min–max		22.7–206	4.4–280.3	78.0–726	33.3–88.3
Mean ± SD per leaf area (g/m^2 year)		246 ± 164 [ab]	325 ± 214 [ab]	540 ± 438 [b]	154 ± 46 [aA]
O_2 production per tree (kg), min–max		16.6–150 [ab]	3.2–204 [ab]	56.7–529 [b]	24.3–64.3 [aA]
Mean ± SD per leaf area (g/m^2 year)		179 ± 119 [ab]	237 ± 156 [ab]	393 ± 319 [b]	112 ± 33 [aA]
Air pollutant removal [1] Mean ± SD per leaf area (mg/m^2 year)			Min–max **per tree** (g/year)		
24.3 ± 0.1	**CO**	1.7–21 [a]	10.6–30.1 [b]	4.00–23.0 [a]	7.50–10.9 [aA]
773 ± 1	**O_3**	52.9–670 [a]	339–959 [b]	127–731 [a]	240–347 [aB]
509 ± 1	**NO_2**	34.9–442 [a]	223–631 [b]	83.4–482 [a]	158–229 [aB]
144 ± 1	**SO_2**	9.8–125 [a]	62.9–178 [b]	23.5–136 [ab]	44.5–64.4 [abB]
426 ± 1	**PM_{10}**	29.2–369.5 [a]	187–528 [b]	69.8–403 [a]	132–191 [aB]
42.7 ± 0.1	**$PM_{2.5}$**	2.9–37.1 [a]	19.0–53.0 [b]	7.00–40.4 [a]	13.3–19.2 [bB]

Jardim das Comunidades, Loulé		***Ceratonia siliqua***	***Olea europaea***	***Pinus pinea***
Leaf area per tree (m^2), min–max		130–507	36.8–408	186–530
C storage per tree (kg), mean ± SD		2339 ± 1163	2041 ± 1799	448 ± 275
Min–max		768–4093	216–5095	187–939
CO_2 sequest. per tree (kg/year), min–max		7.3–36.8	34.7–1659	229–280
Mean ± SD per leaf area (g/m^2 year)		17.8 ± 13.7 [a]	703 ± 759 [b]	255 ± 18.7 [abB]
O_2 production per tree (kg), min–max		2.1–3.8 [a]	5.0–101 [b]	37.8–95.3 [abB]
Mean ± SD per leaf area (g/m^2 year)		13.3 ± 10.3 [a]	512 ± 553 [b]	185 ± 14 [abB]
Air pollutant removal [1] Mean ± SD per leaf area (mg/m^2 year)			Min–max **per tree** (g/year)	
57.1 ± 0.1	**CO**	7.4–28.9 [a]	2.1–23.3 [a]	10.6–30.2 [aB]
1724 ± 1	**O_3**	226–884 [a]	64.0–711 [a]	324–923 [aA]
140 ± 1	**NO_2**	18.2–71.1 [a]	5.2–57.2 [a]	26.1–74.2 [aA]
105 ± 1	**SO_2**	13.6–53.1 [a]	3.8–42.7 [a]	19.5–55.5 [aA]
374 ± 1	**PM_{10}**	48.5–190 [a]	13.8–153 [a]	69.6–198 [aA]
28.3 ± 0.6	**$PM_{2.5}$**	3.7–14.4 [a]	1.0–11.6 [a]	5.3–15.0 [aA]

Values with the same letter (a, b, or ab) do not differ significantly from one another according to Duncan's test ($p < 0.05$). In the case of *P. pinea*, for each of the factors, values with the same capital letter (A or B) do not differ significantly from one another according to Student's *t*-test ($p < 0.05$). [1] The air pollution removal calculation was based only on the total leaf area, not considering the intrinsic properties of each species. The pollution data were from the APA's stations in the vicinity of both green spaces and assuming that pollutant concentration was the same throughout the day.

3.1.1. Parque da Cidade, Porto

M. excelsa is an ornamental species widely used in coastal areas due to its robustness and resistance to maritime influence and drought-prone coastal environment. In Porto, this was the species with the highest efficiency for CO_2 sequestration per leaf area (540 ± 438 g/m^2 per year), and O_2 production per leaf area (393 ± 319 g/m^2 per year). In decreasing order, the CO_2 sequestration and O_2 production quantified per leaf area by species studied in Porto (Table 2) were *M. excelsa* > *P. hispanica* ≅ *C. lusitanica* > *P. pinea*. The studied trees of *M. excelsa* also presented the highest carbon storage capacity (4563 ± 3163 kg).

Regarding the removal of atmospheric pollutants, characteristics of the species such as leaf size and structure, wax content, ultrastructure, thickness, pubescence, and surface roughness, but also climatic conditions such as precipitation, wind, and quantity and composition of atmospheric pollutants can affect plant efficiency [44,48,49]. The *P. hispanica* trees were significantly more efficient ($p < 0.05$) in air pollutant removal (CO, O_3, NO_2, SO_2, PM10, and PM2.5) in Porto, because they present a more favorable leaf morphology to air pollutant deposition and at the same time the largest leaf areas among the sampled trees. Recent studies performed in two European cities (Rimini and Krakow) emphasized that the complex dynamics of PM accumulation, wash-off, and resuspension affect the vegetation contribution to air quality, and during a non-precipitation month (July), reported that species with basal leaves, as in the case of *Platanus hispanica*, showed greater PM 10–100 accumulation than the median and apical ones [49].

However, some limitations were found in the air pollution removal calculation in the i-Tree. Although the intrinsic characteristics of each species condition its ability to remove air pollutants [44,48,49], this aspect is not included in the i-Tree model. For each tree species, the total removal of air pollutants is calculated based on the total leaf area only, not considering, e.g., leaf properties such as hair and wax cover. Furthermore, pollution data were derived from an APA's station in the vicinity of the green space and assuming that pollutant concentration was the same throughout the day. This is a critical consideration, because the efficiency of vegetation to remove air pollutants at a local scale depends on pollution concentration [15].

3.1.2. Jardim das Comunidades—Almancil, Loulé

These drought-tolerant tree species may be particularly interesting in a climate-change scenario because they are naturally adapted to warmer climates and to water stress [50]. Our results in Loulé also confirmed significant differences ($p < 0.05$) in their efficiency for CO_2 sequestration and O_2 production. In decreasing order, the CO_2 sequestration and O_2 production quantified per leaf area and by species (Table 2) were *O. europaea* > *P. pinea* > *C. siliqua*. Studies on these species in urban spaces are scarce, but there has been some previous work on their carbon sequestration potential in Mediterranean forests. The carbon sequestration by olive groves was quantified in southern Spain in the range of 7.52 to 15.05 t CO_2/ha year^{-1} [51], in central Italy as 1.507 t CO_2/ha year^{-1} for the first 11 years of the olive grove [52], and in Creta as 9.18 CO_2/ha year^{-1} [53]. In the Algarve region, the carbon sequestration by *C. siliqua* was estimated as 0.668 t CO_2/ha [45], and other authors [50] showed that under dry-farming systems, carbon sequestration by *C. siliqua* and *O. europea* can function as a novel ecological economic incentive that may potentiate a new income source for farmers while assuring ecosystem services. In different regions of Portugal, the biomass allometry and carbon factors for *P. pinea* were studied, emphasizing the importance of species-specific methods for stand-level carbon estimates, showing that *P. pinea* stands are important carbon stocks, especially mature stands in the reproductive stages [54].

In our work in Loulé, among the studied species, *C. siliqua* presented higher values for carbon storage, maybe because, like *M. excelsa* in Porto, it is a slow-growing species that usually accumulates more carbon than the fast-growing trees [50,55]. The carbon storage per tree of *C. siliqua* ranged between 768 and 4093 kg, higher than reported before for the Algarve region [50] as 675 kg for trees over 50 years old and as 231 kg for trees over 40 years old. Among the studied species, *P. pinea* showed a trend to sequester larger amounts of air pollutants (CO, O_3, NO_2, SO_2, PM10, and PM2.5), but no statistically significant differences were found ($p > 0.05$). Previous studies about particulate pollution capture by woody species in Italy and Poland [49] also revealed that needle-leaved species such as *P. pinea* should be preferred, as they displayed the higher potential for air quality amelioration.

3.1.3. Comparison of the Role of *P. pinea* in Porto versus Loulé

Comparing the results obtained for *P. pinea* in these two Portuguese urban green spaces, we confirmed that different environmental conditions significantly affect ($p < 0.05$) its efficiency for CO_2 and O_2 production per leaf area, reinforcing previous studies in different Portuguese *P. pinea* stands [54]. Our values were higher for *P. pinea* in Loulé (CO_2 sequestration = 255 $\pm$ 18.7 g/m^2 year and O_2 production = 185 $\pm$ 14 g/m^2 year) than in Porto (CO_2 sequestration = 154 $\pm$ 46 g/m^2 year and O_2 production = 112 $\pm$ 33 g/m^2 year). Assuming that water and nutritional tree needs are assured in both urban green spaces and that the condition of the canopies is similar, these differences should be related to the higher photosynthetic rate in Loulé due to higher insolation levels than Porto [42,43]. Some previous studies also found that under the climate conditions of high temperature and low rainfall, scattered small-scale green spaces like Jardim de Almancil in Loulé tend to have higher carbon sequestration performance [38]. Other studies in Chinese urban green spaces [46] included the contribution of shrub vegetation and reported that the highest carbon sequestration performance was achieved when the ratio of trees to shrubs was four.

The *per capita* green space area can be considered a human activity indicator negatively related to anthropogenic pressure, and the global standard is at least 20 m^2 *per capita* [56]. The more urbanized areas are, the more intense the human activities and the respective environmental impacts [57,58]. Globally, urban vegetation can play a crucial role in reducing those impacts, e.g., in the USA, trees and shrubs in urban areas adsorb around 215,000 t/year of PM10 [19]. The *per capita* green space area in Loulé is around 600 times that in Porto (Table 1), where air pollution due to road traffic is considered a main environmental constraint. The type of air pollutants and their respective concentrations in the atmosphere affect plants' behavior upon their removal [44,45,49]. In our study, *P. pinea* trees removed greater quantities (g/year) of air pollutants directly related to the use of fossil fuels (NO_2, SO_2, PM10, and PM2.5) in Porto than in Loulé.

3.1.4. Hydrological Effects of Urban Trees

Our results are in agreement with previous studies, e.g., [20,48,59], that urban trees can be an important force not only for carbon sequestration and air pollutant removal but also to improve the urban water cycle if appropriate management measures and planning solutions are adopted. The change in precipitation patterns is one of the most felt effects of climate change in the Mediterranean, including Portugal [60], namely, the decrease in mean annual precipitation. In recent years, water availability has varied between situations of severe scarcity and extreme abundance due to heavy precipitation events that cause urban flooding with serious human and material damage. Green urban infrastructure can collect and temporarily retain these sudden floods, allowing the discharge peak to flatten [59,61].

We verified that the studied species play an important role in the urban water cycle of both cities through water-flow regulation (Table 3). In Porto, with a mean annual precipitation of 1100 mm [62], *P. hispanica* was the species that most affected the quantified hydrological parameters, e.g., the biggest sampled tree can intercept 13.1 m^3/year and avoid runoff of 2.6 m^3/year. Similar results were obtained for *Platanus orientalis* in recent studies in Mashhad, Iran [48]. In Loulé, with a lower mean annual precipitation, about 600 mm [62], the effects of trees on water intercepted and runoff avoided were lower; however, through their transpiration, trees can make an important contribution to increasing atmospheric humidity and attenuating temperature peaks [20], which is the main environmental constraint for Loulé (Table 1).

Table 3. Structure of trees and their hydrological effects in public spaces in Loulé and Porto.

Parque da Cidade, Porto	*Cupressus lusitanica*	*Platanus hispanica*	*Metrosideros excelsa*	*Pinus pinea*
DBH, cm	Min–max 25.5–137	Min–max 62.0–197	Min–max 25.5–119	Min–max 40.7–65.3
Height, m	11.3–18.8	11.9–20.4	8.5–13.8	9.2–15.4
Crown height, m	6.8–14.2	6.9–15.0	6.4–11.4	2.9–9.1
Potential evapotranspiration, m^3/year	4.3–54.1	27.3–77.3	10.2–59.0	19.3–28.0
Evaporation, m^3/year	0.7–9.1	4.6–13	1.7–9.9	3.3–4.7
Transpiration, m^3/year	1.3–16.1	8.1–23	3.0–17.6	5.8–8.3
Water intercepted, m^3/year	0.7–9.1	4.6–13.1	1.7–10.0	3.3–4.7
Runoff avoided, m^3/year	0.1–1.8	0.9–2.6	0.3–2.0	0.7–1.0

Jardim das Comunidades, Loulé	*Ceratonia siliqua*	*Olea europaea*	*Pinus pinea*
DBH, cm	Min–max 56.0–127	Min–max 27.7–109	Min–max 33.0–67.0
Height, m	6.8– 11.2	4.2–8.9	8.9–9.9
Crown height, m	5.1–9.8	2.7–6.8	5.1–7.0
Crown width, m	7.5–15.9	4.8–11.5	7.9–12.1
Potential evapotranspiration, m^3/year	16.6–64.8	4.7–52.1	23.7–67.7
Evaporation, m^3/year	0.6–2.3	0.2–1.8	0.8–2.4
Transpiration, m^3/year	8.8–34.5	2.5–27.8	12.7–36.1
Water intercepted, m^3/year	0.6–2.3	0.2–1.9	0.9–2.4
Runoff avoided, m^3/year	0.1–0.5	0.1–0.4	0.2–0.6

3.2. Carbon Sequestration by Nature in the Two Urban Contexts

Considering the number of inhabitants in each urban area and respective carbon emissions *per capita* (Table 1), the city of Porto and the Municipality of Loulé emitted in 2020, respectively, 472,872 and 115,008 t CO_2e. According to these values, to neutralize the carbon emissions of the two cities, a much larger number of trees would be needed, which would take up space that is currently unavailable.

As expected, our results show that the efficiency of the different tree species is not the same and that mixed native species in cities can be more valuable than monoculture plantations to ensure different ecosystem services, preserve habitats and reduce biodiversity loss [23]. Moreover, it is important to create new solutions in cities to integrate other types of autochthonous vegetation, such as some shrub species, that take up less space than trees and contribute to urban ecosystem services [23,38,63].

Analyzing these results during the SLI program, youths understood the role of different tree species in supplying ecosystem services, namely, their efficiency in CO_2 sequestration and air pollutant removal from the urban atmosphere, and the need to maintain biodiversity in cities.

After this exercise, activators challenged innovators to develop new concepts for technological solutions to improve nature's role in carbon sequestration and air pollutant removal, which, together with the reduction of CO_2 emissions, can accelerate carbon neutrality in cities.

The main research question at this time was: How can technological innovation improve carbon sequestration by nature in your city?

3.3. Technology and Nature towards Carbon Neutrality

The definition of the biodevice concept has evolved to be innovative while encompassing the different morphologies it could assume to respond to the needs of different places in the city, always based on a co-design process. It was decided that a biodevice is a cyber-physical product to sequester carbon (CO_2e) and atmospheric pollutants that quantifies and communicates sequestered carbon in real time. Being bio-inspired, these devices incorporate technological components to improve natural processes' efficiency in carbon and air pollutant sequestration, respond to variations in urban atmospheric compositions, and communicate with the CEiiA platform. Like living organisms, these devices are "sensitive" to environmental conditions and interpret and adjust to them, operating in a homeostatic way. The theoretical assumption is that biodevices can sequester carbon and remove atmospheric pollutants with greater efficiency than urban vegetation, thanks to the forced circulation of atmospheric air through plant tissues of native species selected for their morphophysiological and physiological characteristics [24,64]. They are supported by vascular and avascular plants (shrubs and mosses) and "transparent technology", which is highly efficient in accelerating vegetal physiology to remove mainly CO_2, NOx, O_3, SO_2, $PM_{2.5}$, and PM_{10}. The sensors incorporated in the biodevice collect information about pollutant concentrations and send it to the CEiiA's platform. When pollutant concentrations reach alert values according to WHO air quality guidelines (e.g., NO_2 = 10 μg/m^3; SO_2 = 40 μg/m^3; CO = 4 mg/m^3; PM_{10} = 15 μg/m^3; $PM_{2.5}$ = 5 μg/m^3), a real-time system is activated that forces the polluted air to pass through the plants and optimizes the phytoremediation of these toxic substances that threaten the health of the urban population.

From the young's perspective, biodevices should be natural elements in the city and perfectly integrated with the urban environment, according to their requirements and functionalities, as follows.

- They should be modular and reconfigurable, responding to the atmospheric pollutants in different parts of the city.
- They should have a cute and innovative design integrated into the city's landscape and optimize the functioning of selected native plants using technology.
- They should be built with low-carbon materials and function with eco-efficiency, including energy autonomy and water reuse for irrigation.

During the last phase of SLI, the innovators worked in an interactive dynamic with the different activators and energizers. Sketches of the biodevice prototypes evolved, trying to respond to the defined requirements and functionalities. Figures 2 and 3 show the results of the biodevice prototypes co-designed by the young people at the end of SLI. The idea is that the devices functioning in a real context are ensured with the support of young generations. In an open knowledge environment, children and young people will be involved in their operation and maintenance by identifying anomalies, reporting problems, disseminating results, etc. This approach induces the social adoption and appropriation of these devices by the entire community. Moreover, data and information about the amount of sequestered carbon and pollutants removed and other indicators will be available to youths, who can transmit the lessons learned to their families, inducing behavioral change.

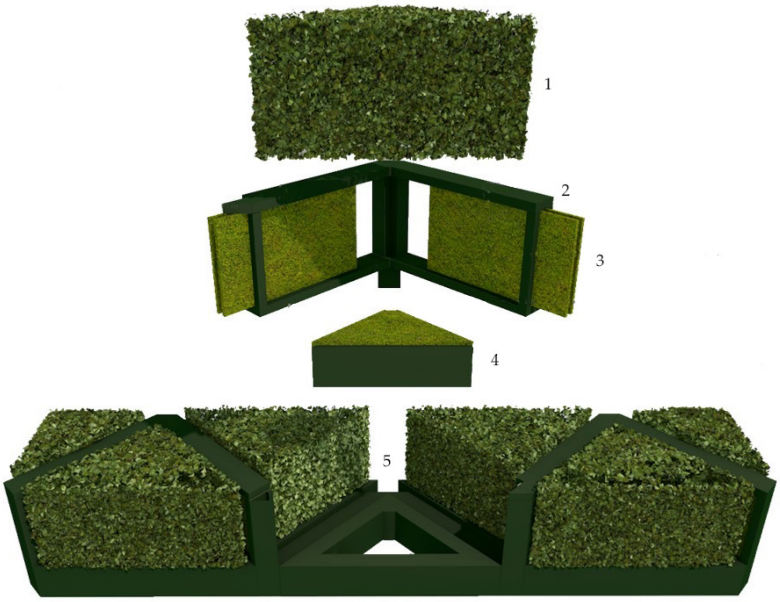

Figure 2. The smart hedge to be placed in a hotspot of air pollution, with electronic sensors and dimensions 1.4 m × 0.80 m × 0.80 m. (1) Autochthonous shrub; (2) rainwater collector; (3) autochthonous moss; (4) container with soil and capillary irrigation; (5) water reservoir.

Figure 3. The biodevice to be placed at a bus stop (1) with electronic sensors and dimensions of 3 m high and 1.13 m area at the base with autochthonous shrubs. (2) Photovoltaic panel; (3) water collector; (4) soil container; (5) water reservoir; (6) autochthonous moss; (7) shading blind.

Making tangible the value of sequestered carbon and stressing, for example, the costs avoided in public health systems is very important for empowering citizens to act, as carbon footprint assessment tools can be the first approach to enhancing climate awareness [48,65].

Data and information stored and shared prove to be a valuable resource for increasing citizen awareness of the value of urban nature and their engagement with initiatives to protect and restore it. Furthermore, cities' aesthetics will be improved by the integration of these kinds of new green areas in urban spaces, increasing biodiversity, and tackling heat waves.

4. Final Considerations

Urban trees ensured the studied ecosystem services in two Portuguese cities in different but complementary ways for people's health and well-being, reinforcing results obtained with various methodological approaches in other cities. For CO_2 sequestration, the best performance was from *M. exelsa* in Porto and *O. europea* in Loulé, and for air pollutant removal and hydrological regulation was from *P. hispanica* in Porto and *P. pinea* in Loulé. The innovators verified the importance of biodiversity and ecosystem services provided by autochthonous tree species in Porto city and Loulé Municipality and the need to increase carbon sequestration to foster carbon neutrality.

Innovative nature-based solutions were discussed to meet young people's expectations and to be strategically integrated for the first time in two Portuguese cities, where the space available for nature has become increasingly smaller. In a multidisciplinary approach, they developed two concepts for innovative biodevices, associating technology with native vegetation to increase CO_2e sequestration by plant biomass. Young people considered that these innovative biodevices to increase CO_2e sequestration in cities should be cyber-physical products of two types: one in the form of a hedge for air pollution hotspots, and the other to be placed at bus stops. Both biodevices were designed to incorporate autochthonous shrubs and mosses, be supplied by rainwater and renewable energies, use recycled plastic support materials, and reduce galvanized steel to the minimum necessary and only in the biodevice for the bus stop. The technological component collects information and manages it in order to increase the biodevice's sensitivity to environmental variations and real-time reaction capacity. The next step is to enroll young people in the prototype building and concept proof with the CEiiA team in a real-city context.

Programs, including nature-based solution learning, have the potential to accelerate youth awareness of the adverse impacts of climate change, leading them to action. By quantifying the role of nature and using innovative technological approaches to accelerate the physiological processes of some autochthonous species with high carbon sequestration potential, young people were empowered to act and reconfigure their vision of the urban ecosystem toward a smart and sustainable city.

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References

1. Database.earth. 2024. Available online: https://database.earth/population (accessed on 5 January 2024).
2. UN-DESA, United Nations Department of Economic and Social Affairs. World Population Prospects 2022. Population Division. Summary of Results. 2022. Available online: https://www.un.org/development/desa/pd/content/World-Population-Prospects-2022. (accessed on 4 September 2023).
3. Brauer, M.; Casadei, B.; Harrington, R.A.; Kovacs, R.; Sliwa, K.; WHF Air Pollution Expert Group. Taking a Stand Against Air Pollution. The Impact on Cardiovascular Disease. *J. Am. Coll. Cardiol.* **2021**, *77*, 1684–1688. [CrossRef]
4. WHO, World Health Organization. Urban Health Initiative. Improving Air Quality and Health in Cities. Health Impacts. 2021. Available online: https://www.who.int/initiatives/urban-health-initiative/health-impacts (accessed on 6 September 2023).
5. Guzmán, O.; Tarím-Carrasco, P.; Suárez-Varela, M.M.; Jiménez-Guerrero, P. Effects of air pollution on dementia over Europe for present and future climate change scenarios. *Environ. Res.* **2022**, *204*, 112012. [CrossRef]
6. Vermeulen, A.; Kutsch, W.L.; Parampil, S.R. Carbon emissions and sinks vary between the years. *Fluxes* **2023**, *2*, 13–17.
7. Intergovernmental Panel on Climate Change—IPCC. Climate Change 2023. Synthesis Report. 2023. Available online: https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf (accessed on 4 December 2023).
8. Kutsch, W.L. Nature-based carbon sinks. *Fluxes* **2023**, *2*, 5–11.
9. Luhtaniemi, M. Forest carbon sinks under pressure. *Fluxes* **2023**, *2*, 19–25.
10. Ritchie, H.; Roser, M. Urbanization. OurWorld in Data.org. 2018. Available online: https://ourworldindata.org/urbanization (accessed on 4 September 2023).
11. United Nations Environment Program. Annual Report 2022. Available online: https://www.unep.org/resources/annual-report-2022 (accessed on 4 September 2023).
12. Sesini, G.; Castiglioni, C.; Lozza, E. New Trendsa an Patterns in Sustainable Consumption: A Systematic Review and Research Agenda. *Sustainability* **2020**, *12*, 5935. [CrossRef]
13. Balogun, A.L.; Tella, A.; Baloo, L.; Adebisi, N. A review of the inter-correlation of climate change, air pollution and urban sustainability using novel machine learning algorithms and spatial information science. *Urban Clim.* **2021**, *40*, 100989. [CrossRef]
14. Coelho, S.; Rafael, S.; Lopes, D.; Miranda, A.I.; Ferreira, J. How changing climate may influence air poillution control strategies for 2030? *Sci. Total Environ.* **2021**, *758*, 143911. [CrossRef] [PubMed]
15. Graça, M.; Alves, P.; Gonçalves, J.; Nowak, D.J.; Hoehn, R.; Farinha-Marques, P.; Cunha, M. Assessing how green space types affect ecosystem services in Porto, Portugal. *Landsc. Urban Plan.* **2018**, *170*, 195–208. [CrossRef]
16. Jong, M.; Joss, S.; Schraven, D.; Zhan, C.; Weijnen, M. Sustainable-smart-resilient-low carbon-eco-knowledge cities; making sense of a multitude of concepts promoting sustainable urbanization. *J. Clean. Prod.* **2015**, *109*, 25–38. [CrossRef]
17. EEA, European Environment Agency. Air Quality in Europe 2022. Web Report. 2022. Available online: https://www.eea.europa.eu/publications/air-quality-in-europe-2022. (accessed on 6 September 2023).
18. WHO, World Health Organization. New WHO Global Air Quality Guidelines. 2021. Available online: https://www.who.int/news/item/22-09-2021-new-who-global-air-quality-guidelines-aim-to-save-millions-of-lives-from-air-pollution (accessed on 7 September 2023).
19. Nowak, D.J.; Greenfield, E.J.; Hoehn, R.E.; Lapoint, E. Carbon storage and sequestration by trees in urban and community areas of the United States. *Environ. Pollut.* **2013**, *178*, 229–236. [CrossRef]
20. Li, L.; Bergen, J.M. Green infrastructure for sustainable urban water management: Practices of five forerunner cities. *Cities* **2018**, *74*, 126–133. [CrossRef]
21. UNEP. Climate Action. Press Release. 2021. Available online: https://www.unep.org/news-and-stories/press-release/covid-19-caused-only-temporary-reduction-carbon-emissions-un-report (accessed on 4 September 2023).
22. Ahlgren, K.; Kutsch, W.L.; Parampil, S.R. Nature-based carbon sinks have a dual role in climate action. *Fluxes* **2023**, *2*, 7–12.
23. Spotswood, E.N.; Beller, E.E.; Grossinger, R.; Grenier, J.L.; Heller, N.E.; Aronson, M.F.J. The Biological Deserts Fallacy: Cities in Their Landscapes Contribute More than We Think to Regional Biodiversity. *BioScience* **2021**, *71*, 148–160. [CrossRef]
24. Othman, R.; Kasim, S.Z.A. Assessment of Plant Materials Carbon Sequestration Rate for Horizontal and Vertical Landscape Design. *Int. J. Environ. Sci. Dev.* **2016**, *7*, 410–414. [CrossRef]
25. Xu, L.; Shi, Y.; Fang, H.; Zhou, G.; Xu, X.; Zhou, Y.; Tao, J.; Ji, B.; Xu, J.; Li, C.; et al. Vegetation carbon stocks driven by canopy density and forest age in subtropical forest ecosystems. *Sci. Total Environ.* **2018**, *631–632*, 619–626. [CrossRef]
26. European Commission, EC. European Week of Regions and Cities. Implementing Inclusive and Just Nature-Based Solutions: An Interactive Workshop. 2022. Available online: https://europa.eu/regions-and-cities/programme/2022/sessions/2353 (accessed on 4 September 2023).
27. Li, X.; Hu, Z.; Cao, J.; Xu, X. The impact of environmental accountability on air pollution: A public attention perspective. *Energy Policy* **2022**, *161*, 112733. [CrossRef]
28. Kim, S.E.; Maamoun, N.; Gopinathan, N.; Urpelainen, J. The Sorry State of Research on Public Opinion about Air Pollution: A Systematic Review. *SSRN Electron. J.* **2021**. [CrossRef]
29. Zhang, S.; Li, Y.; Hao, Y.; Zhang, Y. Does public opinion affect air quality? Evidence based on the monthly data of 109 prefecture-level cities in China. *Energy Policy* **2018**, *116*, 299–311. [CrossRef]
30. Thomaes, S.; Grapsas, S.; Wetering, J.; Spitzer, J.; Poorthuis, A. Green teens: Understanding and promoting adolescents' sustainable engagement. *One Earth* **2023**, *6*, 352–361. [CrossRef]

31. Dabija, D.; Bejan, B.M.; Puscas, C. A qualitative Approach to the Sustainable Orientation of Generation Z in Retail: The Case of Romania. *J. Risk Financ. Manag.* **2020**, *13*, 152. [CrossRef]
32. IUCN. Nature-Based Solutions. 2023. Available online: https://www.iucn.org/our-work/nature-based-solutions (accessed on 8 June 2023).
33. Jordan, C.; Chawla, L. A coordinated research agenda for nature-based learning. In *High-Quality Outdoor Learning: Evidence-Based Education Outside the Classroom for Children, Teachers and Society*; Springer: Cham, Switzerland, 2022; pp. 29–46.
34. Utkarsh, S. Integrating Nature in Education: Unlocking the Potential of Transformative Learning for Sustainability. Available online: https://networknature.eu/product/29478 (accessed on 18 September 2023).
35. UNESCO. Youth Demands for Quality Climate Change Education. 2022. Available online: https://unesdoc.unesco.org/ark:/48223/pf0000383615 (accessed on 18 September 2023).
36. Kuo, M.; Barnes, M.; Jordan, C. Do experiences with nature promote learning? Converging evidence of a cause-and-effect relationship. In *High-Quality Outdoor Learning*; Springer: Cham, Switzerland, 2022; pp. 47–66. [CrossRef]
37. Kleespies, M.W.; Dierkes, P.W. Connection to nature of university students in the environmental field—An empirical study in 41 countries. *Biol. Conserv.* **2023**, *283*, 110093. [CrossRef]
38. Dong, H.; Chen, Y.; Huang, X. A new framework for analysis of the spatial patterns of 15-minute neighbourhood green space to enhance carbon sequestration performance: A case study in Nanjing, China. *Ecol. Indic.* **2023**, *156*, 111196. [CrossRef]
39. IBM Corp. *Released 2020. IBM SPSS Statistics for Windows, Version 27.0*; IBM Corp.: Armonk, NY, USA, 2020.
40. PORDATA. Statistics about Portugal and Europe. 2021. Available online: https://www.pordata.pt/en/home (accessed on 8 June 2023).
41. Portuguese Environment Agency, APA. Distribuição Espacial de Emissões Nacionais. 2020. Available online: https://apambiente.pt/clima/distribuicao-espacial-de-emissoes-nacionais-2015-2017-e-2019 (accessed on 4 September 2023).
42. Porto Municipality, EMAAC. Estratégia Municipal de Adaptação às alterações Climáticas. 2016. Available online: https://ambiente.cm-porto.pt/files/uploads/cms/1613123260-yGpy4093dh.pdf (accessed on 4 September 2023).
43. Loulé Municipality, PMAC. Plano Municipal de Ação Climática. 2021. Available online: https://www.cm-loule.pt/pt/24253/pmac-de-loule.aspx (accessed on 4 September 2023).
44. Weyens, N.; Thijs, S.; Popek, R.; Witters, N.; Przybysz, A.; Espenshade, J.; Gawronska, H.; Vangronsveld, J.; Gawronski, S. The Role of Plant-Microbe Interactions and Their Exploitation for Phytoremediation of Air Pollutants. *Int. J. Mol. Sci.* **2015**, *16*, 25576–25604. [CrossRef]
45. Sæbø, A.; Popek, R.; Nawrot, B.; Hanslin, H.M.; Gawronska, H.; Gawronski, S.W. Plant species differences in particulate matter accumulation on leaf surfaces. *Sci. Total Environ.* **2012**, *427–428*, 347–354. [CrossRef] [PubMed]
46. Wang, Y.; Chang, Q.; Li, X. Promoting sustainable carbon sequestration of plants in urban greenspace by planting design: A case study in parks of Beijing. *Urban For. Urban Green.* **2022**, *64*, 127291. [CrossRef]
47. Snehlata; Rajlaxmi, A.; Kumar, M. Urban tree carbon density and CO_2 equivalent of National Zoological Park, Delhi. *Environ. Monit Assess* **2021**, *193*, 841. [CrossRef] [PubMed]
48. Yousofpour, Y.; Abolhassani, L.; Hirabayashi, S.; Burgess, D.; Sabouni, M.S.; Daneshvarkakhki, M. Ecosystem services and economic values provided by urban park trees in the air polluted city of Mashhad. *Sustain. Cities Soc.* **2024**, *101*, 105110. [CrossRef]
49. Vigevani, I.; Corsini, D.; Mori, J.; Pasquinelli, A.; Gibin, M.; Comin, S.; Szwałko, P.; Cagnolati, E.; Ferrini, F.; Fini, A. Particulate pollution capture by seventeen woody species growing in parks or along roads in two European cities. *Sustainability* **2022**, *14*, 1113. [CrossRef]
50. Correia, P.J.; Guerreiro, J.F.; Pestana, M.; Martins-Loução, M.A. Management of carob tree orchards in Mediterranean ecosystems: Strategies for a carbon economy implementation. *Agrofor. Syst.* **2017**, *91*, 295–306. [CrossRef]
51. Lopez-Bellido, P.J.; Lopez-Bellido, L.; Fernandez-Garcia, P.; Muñoz-Romero, V.; Lopez-Bellido, F.J. Assessment of carbon sequestration and the carbon footprint in olive groves in Southern Spain. *Carbon Manag.* **2016**, *7*, 161–170. [CrossRef]
52. Proietti, S.; Sdringola, P.; Desideri, U.; Zepperelli, F.; Brunori, A.; Ilarioni, L.; Nasini, L.; Regni, L.; Proietti, P. Carbon footprint of an olive tree grove. *Appl. Energy* **2014**, *127*, 115–124. [CrossRef]
53. Vourdoubas, J. Estimation of carbon sequestration from olive tree groves in the island of Crete, Greece. *Int. J. Agric. Environ. Res.* **2020**, *6*, 553–565. [CrossRef]
54. Correia, A.; Tomé, M.; Pacheco, C.A.; Faias, S.P.; Dias, C.; Freire, J.; Carvalho, P.; Pereira, J.S. Biomass allometry and carbon factors for a Mediterranean pine (*Pinus pinea* L.) in Portugal. *For. Syst.* **2010**, *19*, 418–433. [CrossRef]
55. Nair, P.K.R.; Kumar, B.M.; Nair, V.D. Agroforestry as a strategy for carbon sequestration. *J. Plant Nutr. Soil Sci.* **2009**, *172*, 10–23. [CrossRef]
56. UN-Habitat. National Urban Policy. 2018. Available online: https://unhabitat.org/Programme/National-urban-policy (accessed on 9 January 2024).
57. Lifang, C.; Lunche, W.; Sai, Q.; Lihuan, D.; Zhaoduo, W. Impactts of Temperature, Precipitation, and Human Activities on Vegetation and NDVI in Yangtze River Basin. *Earth Sci.* **2020**, *45*, 1905–1917. [CrossRef]
58. Tehrani, N.A.; Farhanj, F.; Janalipour, N. Monitoring the Impacts of Human Activities on Urban Ecosystems Based on the Enhanced UCCLN (EUCCLN) Model. *ISPRS Int. J. Geo-Inf.* **2023**, *12*, 170. [CrossRef]
59. Smith, I.A.; Templer, P.H.; Hutyra, L.R. Water sources for street trees in mesic urban environments. *Sci. Total Environ.* **2024**, *908*, 168411. [CrossRef]

60. Intergovernmental Panel on Climate Change, IPCC. AR6 Synthesis Report: Climate Change. 2023. Available online: https://www.ipcc.ch/report/sixth-assessment-report-cycle/ (accessed on 6 September 2023).
61. Mentens, J.; Raes, D.; Hermy, M. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? *Landsc. Urban Plan* **2006**, *77*, 217–226. [CrossRef]
62. Portuguese Institute for Sea and Atmosphere. Climate Monitoring. 2022. Available online: https://www.ipma.pt/en/oclima/monitorizacao/index.jsp?selTipo=m&selVar=tx&selAna=an&selAno=2020 (accessed on 6 September 2023).
63. Jia, X.; Han, H.; Feng, Y.; Song, P.; He, R.; Liu, Y.; Wang, P.; Zhang, K.; Du, C.; Ge, S.; et al. Scale-dependent and driving relationships between spatial features and carbon storage and sequestration in an urban park of Zhengzhou, China. *Sci. Total Environ.* **2023**, *894*, 164916. [CrossRef]
64. Carbognani, M.; Tomaselli, M.; Petraglia, A. Interactions and Covariation of Ecological Drivers Control CO_2 Fluxes in an Alpine Peatland. *Wetlands* **2023**, *43*, 44. [CrossRef]
65. Wagner, O.; Tholen, L.; Nawothnig, L.; Albert-Seifried, S. Making school-based GHG-emissions tangible by student-led carbon footprint assessment program. *Energies* **2021**, *14*, 8558. [CrossRef]