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Reforestation of Urban Districts in Mediterranean Climate: New Decarbonization Models for Cities

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The transformation of cities and urban and peri-urban neighborhoods into flexible, adaptive, and sustainable organisms, in the context of the latest European policy proposals on climate, energy, transportation, land use and resources, have become today's issues that can no longer be postponed. These issues introduce the focus that has been experimentally analyzed through the study, census, and subsequent cataloging of more than 100 tree and shrub species found in the Mediterranean basin according to their carbon uptake and storage capacities, defining a synoptic framework useful, for actors in the field, in silviculture and urban reforestation. These solutions led to the compilation of a detailed database through experimental research that took place in a public housing neighborhood of the Municipality of Rome Capital, the subject of a proposed urban redevelopment, numerically quantifying the carbon absorbed and stored for each individual species. The topic is of great scientific relevance considering national and European strategies and the proposal, put forward by the European Commission, on the New EU Forestry Strategy Fit for 55.

Keywords: *urban reforestation, urban district, natural carbon sinks*

Introduction

Our planet is experiencing momentous environmental alterations that are increasingly affecting the way we live and inhabit.

In the face of climate change, increasing impacts from carbon emissions, and the growing European energy crisis-accentuated recently by the rising cost of sourcing and supplying natural gas on which member countries depend for more than 42 percent-urgent policies and actions are needed to make urban dwellers more resilient and responsible to the impacts derived from the sudden economic, social and environmental change. Mitigation measures (but also adaptation measures, especially if integrated with them) to keep global temperature rise within 1.5°C could avoid some of the most devastating impacts of ongoing climate change, but we know that, on the one hand, their implementation lags far behind the roadmap hoped for in 2015, and on the other, that if average temperatures were to reach an increase of 1.7-1.8 °C, ecosystems now considered vulnerable would double the likelihood of extinction, increasing tenfold when +3 °C is reached (IPCC 2022). As concern grows, the urgency of serious decarbonization, primarily in cities, increases. Surveying the existing building stock, more than 65 percent of which predates the first inherent energy-saving law (ISTAT 2021), obliges us to respond to European commitments aimed at reducing climate-changing gas

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emissions-primarily from energy consumption for heating and cooling-in a bid to decarbonize the sector. Continuous technological innovation has led to the development of increasingly efficient software capable of simulating, with greater accuracy, real behavior characteristics. This makes it possible, within a defined 'virtual' space, to investigate the environmental and energy performance of a building artifact within an urban district, defining real intervention scenarios (Erell et al. 2011). The achievement of high performance of fluid dynamic behaviors in indoor comfort and the very idea of 'sustainability,' falling under the growing developments of Information and Communication Technology (ICT) tools (Maksimovic 2018), require specific repeated analyses with alternative technical solutions implemented during the decision-making process, which necessitate an increasingly active role of digital technologies and design managed by scientific parameters (Boeri et al. 2017). Such profound changes require new models of responsible and sustainable development that can improve the quality of life while respecting the environment (Battisti and Santucci 2020). The architecture sector is at the center of such change, claiming, forcefully, a new integrated and cross-cutting approach within the entire process of planning, design, and production, fully integrated with the innovative reach of the digital transition (Abdolhosseini Qomi et al. 2016). Among urban regeneration measures aimed at decarbonizing districts, we can count afforestation and reforestation practices, as well as environmental technology solutions, primarily Nature-based Solutions, capable of offering answers to climate change, as well as to the quality of living, issues increasingly linked to urban growth (Tucci 2018). The strategy of incentivizing green infrastructure actions and solutions is part of a broader scientific debate regarding the development of integrated dissemination methodologies and tools aimed at the sustainability of urban transformations from a deep renovation perspective (Andreucci 2017). The originality of the contribution can be identified in the preparation of synoptic framework, useful to actors in the urban reforestation and forestry sectors, of green solutions, with the primary goal of contributing to halving carbon emissions by 2030 and achieving carbon neutrality by 2050 (IPCC 2019). This approach aims to define and catalogue solutions and strategies to date aimed at reducing carbon emissions in urban districts, which are responsible for 36 percent of final energy consumption and 39 percent of total global carbon dioxide emissions (IPCC 2021). The most recent reports confirm for decades to come an increase from the population living in urban areas, especially in underdeveloped areas. In addition, such urban areas are marked by higher average air temperatures, a lack of regimentation of the water cycle, high emissions of CO_2 and other climate-altering gases from the anthropogenic component, having overall a low level of biodiversity. The construction sector, responsible for 39 percent of the world's total carbon emissions, 11 percent of which are derived from the production of construction materials such as steel, cement, and glass, strongly needs strategies, solutions, and actions that have not yet been systematically established in the built environment. Among the urban regeneration measures aimed at decarbonizing districts, with multiple solutions based on a main strategic axis defined as 'green,' we can count afforestation and reforestation practices, as well as environmental technology solutions, primarily nature-based solutions,

capable of offering answers to the problem of loss of Natural Capital and quality of living increasingly linked to urban growth. This is the thrust of the European Commission's FitFor55 Climate Plan, which aims to improve the quality, quantity, and resilience of green areas with the reforestation of European forests by 3 billion trees to be planted by 2030, and specific national targets for expanding natural carbon stores will be hoisted on each member state (Bionova 2018). Plants are the only living things that produce oxygen unlike animals that use it without replenishing it and emitting CO_2. Scientists estimate that a single tree can absorb carbon dioxide at a rate of 21.8 kg/year and release enough oxygen into the atmosphere to sustain 2 humans but certainly not their vehicles and activities. The idea of using nature to improve urban sustainability through the creation of green infrastructure, parks and gardens, green areas, river and ecosystem restoration is increasingly vital to address these sides effectively and adaptively. Trees, in fact, with their canopies and shading, are the most effective weapon available to cities to promote diffuse cooling and prevent the absorption of heat during the day and its release into the atmosphere at night. In this way, parks gardens, hilar but also potted trees act against the main causes of climate change while generating quality and livability of public spaces in cities. However, the mitigating power of plant species with respect to pollutants is differentiated in relation to the individual characteristics they are endowed with, which can take the form of aptitudes for carrying out specific actions:

- reduction of pollutants in the atmosphere through the mechanism of photosynthesis, pollutant compounds are eliminated by absorption and subsequent metabolization;
- capture of particulate matter (PM_{10}, PM_5, $PM_{2.5}$) due to the presence of hairs, roughness and waxes on the leaf surface that function as a biological filter;
- phytoremediation, consisting of the extraction of pollutant compounds from the soil to accumulate them in the roots and leaves or the biodegradation of organic contaminants from soils by exploiting the synergy with microorganisms present around and within their roots (phytoremediation), which results in what is known as 'phytostabilization';
- phytodepuration, consisting of the capture and stabilization/demolition of water pollutants.

These solutions have the advantage of simultaneously providing environmental, social and economic benefits and helping to build resilience. These are actions inspired, supported, or copied from nature. The use and exploitation of these solutions have mostly gone to development mechanisms whose effects are known, but increasingly new situations are being explored by mimicking how nonhuman organisms and communities cope with extreme events (Antonini and Tucci 2017). Nature-based solutions use nature's features and complex system processes, such as its ability to store carbon and regulate water luxury to achieve desired outcomes, such as disaster risk reduction, improved human well-being, and socially inclusive green growth. These nature-based solutions are ideally energy and resource

efficient and resilient to change. Such knowledge makes it possible to unravel how nature works, benefiting all people and transforming these sides into actions for sustainable green growth, the success of which is, however, contingent on the degree to which they are adapted to local conditions.

The strategy of incentivizing green infrastructure actions and solutions is part of a broader scientific debate regarding the development of integrated dissemination methodologies and tools aimed at the sustainability of urban transformations from a deep renovation perspective.

The adoption of actions aimed at targeted and designed urban reforestation in climatic-Mediterranean conditions results in climate mitigation effects with a calculable and verifiable CO_2 subtraction, a widespread improvement of the local microclimate, a net increase in ecosystem services and a general increase in natural carbon sink; these results can be achieved if the use of tree and shrub masses is done by resorting to native, locally native species with high environmental mitigation capacity.

This objectives, achievable through a rehabilitation of urban surfaces (brownfield), where biological processes capable of storing large amounts of carbon take place, introduce the focus that has been experimentally analyzed through the study, census and cataloging of more than 100 tree and shrub species present in the Mediterranean basin according to their carbon absorption and storage capacities, defining a synoptic framework useful, for the actors in the field, in the field of forestry and urban reforestation.

Methodology/Materials and Methods

The contribution illustrates one of the main results of the research whose general objective was the creation of a database of the main tree and shrub species present in the Metropolitan City of Rome Capital, with high environmental mitigation and climate-altering gas absorption capacities, which could be made available to local authorities, useful for private citizens and businesses. This methodological tool is aimed at making known the CO_2 absorption and storage values of each species analyzed. A 'taxonomic storage quali-quantitative index' was introduced in the drafting of the database, aimed at raising awareness of the use of native tree species with high environmental mitigation capacity, which are therefore more sustainable in terms of environmental mitigation (improvement of the thermo-hygrometric well-being of the planting area as well as selective filtering capacities to urban air pollutants). The structuring of the index was carried out, primarily, based on a literature review taken from the ActaPlantarum and Dryades sitographies, from 2007 and 2021, respectively (Pignatti et al. 2017, City of Rome 2021) aimed at knowing the tree and shrub species present in the metropolitan area and quantifying their degree of carbon uptake. It should be pointed out that herbaceous species were excluded from this analysis, given their reduced CO_2 absorption capacity compared to tree and shrub species. Field surveys in the Metropolitan City of the City of Rome Capital, in both urban and peri-urban areas, enabled the list to be enriched from that extracted from the above

literature. Next, a database was created using Excel Suite Office 2020 software where, for each plant species, the following information is reported.

1) Scientific name of the species, i.e., Linnean binomial (composed of: generic epithet, specific epithet, and patronymic, i.e., name of the author who first discovered the species); the nomenclature is taken from ActaPlantarum and Dryades as of 2007 and 2021, respectively.
2) Photograph of the species (from ActaPlantarum).
3) Number of individuals per species found in the Metropolitan City of Rome Capital.
4) Exotic status (Galasso et al. 2018): autochthonous when the presence of the species is spontaneous and therefore does not depend on the presence of humans, or allochthonous when its presence is linked, intentionally or accidentally, to human action.
5) For allochthonous species, the time of introduction according to the two currently recognized categories:
   5a) Archeophytes, species introduced before 1492, that is, before European colonialism after the discovery of America.
   5b) Neophytes, species introduced after 1492.
6) For allochthonous species, naturalization status:
   6a) Random, species that develop and reproduce spontaneously but fail to form stable populations.
   6b) Naturalized, species that form stable stands independent of the contribution of new propagules by humans.
   6c) Invasive-a subgroup of naturalized species capable of spreading rapidly, at considerable distances from their original propagule sources, and thus with the potential to spread over large areas.
7) Simplified chorotype, according to an initial classification reported by ActaPlantarum and reclassified here in order to homogenize geographic macroareas of origin (Table 1).
8) Biological form, according to the classification reported by ActaPlantarum; categories are defined on the basis of adaptations for bud protection during the adverse season: 'Arboreal Phanerophytes' (P scap), woody plants with an arboreal habit and buds set at heights above two meters above the ground; 'Nano-Panerophytes' (NP), woody plants with perennial buds set between 20 cm and 2 m above the ground; 'Bushy Phanerophytes' (P caesp), woody plants with a bushy habit; 'Rhizomatous Geophytes' (G rhiz), perennial plants equipped with a rhizome, an underground stem from which roots and aerial stems branch out each year.
9) Use, according to the following types of uses: artisanal, edible, cosmetic, forestry, melliferous, medicinal, ornamental, reforestation, screening.
10) CO_2 absorption capacity, according to the 20-year CO_2 storage analysis, in tons, of each individual tree/shrub species (Toscana Region 2018).

Table 1. *On the Right of the Table the Chorotype According to the Classification Reported by Actaplantarum, on the Left the Reclassified Chorotype*

Actaplantarum chorotype	**Reclassified chorotype**
North America	Alien
South America	Alien
Asia	Alien/Eurasian
Western Asia	Eurasian
East Asia	Alien
Australia	Alien
Europe	Mediterranean
Southern Europe	Mediterranean
Asian European	Eurasian
Asian European, Euro-Asian, North Africa	Eurasian
European Caucasian	European-Caucasian
Eurosiberian	Eurosiberian
Macaronesia	Mediterranean
Mediterranean	Mediterranean
Naturalized	Eurasian/Alien/Euroepan-Cuacasian
Coutries in the tropical belt Africa and Asia	Alien

Source: Giampaoletti 2022.

Sperimentation

The Experimentation on the Case of the PdZ of San Basilio in Rome

The public housing district of St. Basil (designer M. Fiorentino, 1951-1955) is in City Hall IV of the Municipality of Rome Capital, within which we find 4,680 ERP housing units (Figure 1) with a total area of 135,574 square meters of which 53,473 square meters are classified as open space.

Figure 1. *Aerial Photo of the San Basilio PdZ*

Source: Cartoteca PDTA, 'Sapienza' Università di Roma, 2014.

Such housing is managed 70% by ATER - Azienza Territoriale per l'Edilizia Residenziale pubblica (former IACP - Istituto Autonomo Case Popolari) and 30% by the municipality, locating precisely in the former PDZ 02V - San Basilio. In recent years, the crowding index has been drastically reduced, the young households in the neighborhood itself are looking elsewhere for housing due to a strong deficit of primary services, as well as an overall degradation of open spaces, conditions that have generated, over time, a reduction in the real estate value of housing, often encouraging the establishment of conditions of organized petty crime.

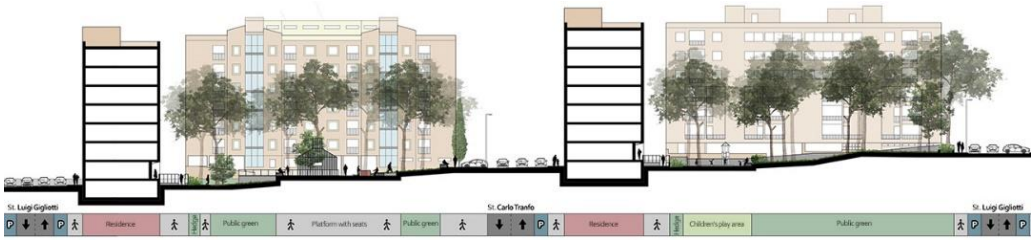
The study and analysis of the 'green' aspects of the PdZ (Figure 2), following site visits that took place over several days to learn about, analyze and census the tree and shrub species that make up the area under study, enabled the census and cataloging of 22 tree and shrub species, with a predominance of 'Ailanthus altissima', 'Cedrus atlantica', 'Robinia pseudoacacia' and 'Eucalyptus camaldulensis', for a total of 374 medium - and tall-trunked individuals with a total storage of 360.576 $KgCO_2eq$/year (Table 2).

Table 2. *Classification and Numerical Quantification of Tree and Shrub Species in the San Basilio PdZ*

Species	**Number registered**
Acacia dealbata	4
Acer platanoides	10
Acer saccharinum	21
Ailanthus altissima	31
Cedrus atlantica	9
Citrus limon	2
Cupressus sempervirens	17
Eucalyptus camaldulensis	12
Fagus sylvatica	41
Junglans regis	11
Laurus nobilis	70
Liriodendron tulipifera	6
Magnolia grandiflora	4
Malus domestica	3
Olea europaea	6
Pinus nigra	4
Pinus pinea	30
Platanus hyspanica	6
Prunus avium	5
Quercus ilex	10
Robinia pseudoacacia	34
Tilia cordata	38
Total	**374**

Source: Giampaoletti 2022.

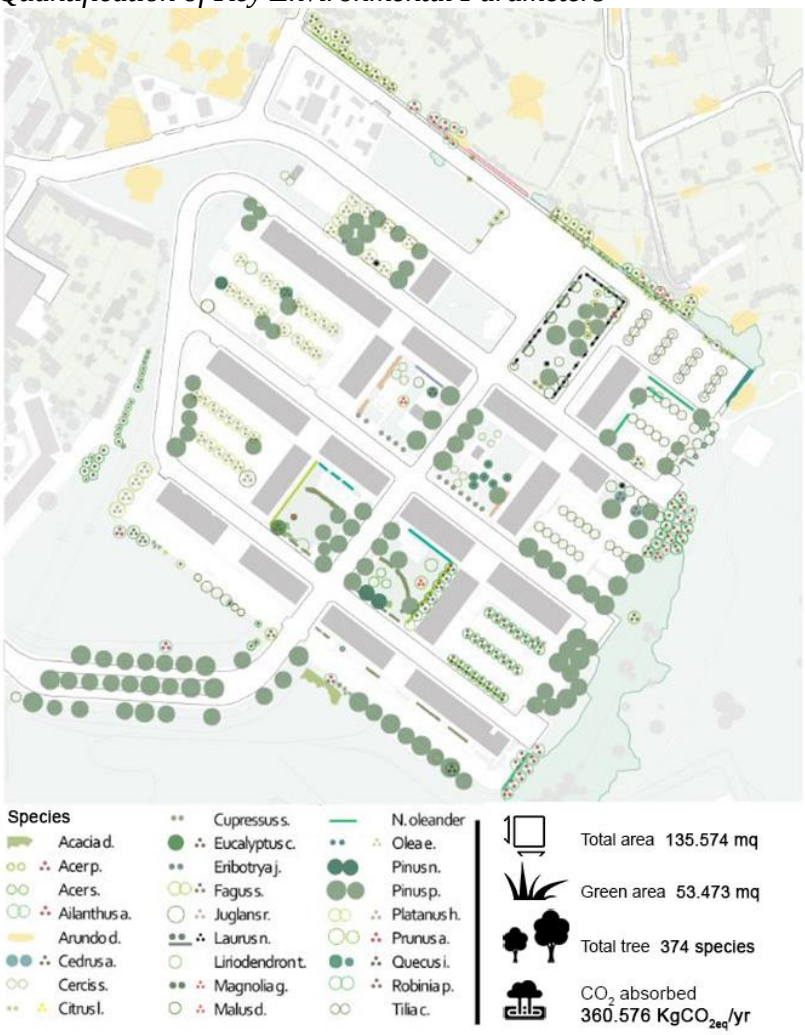
Figure 2. *Section Profile of the San Basilio PdZ between Luigi Gigliotti Street and Carlo Tranfo Street*



Source: Giampaoletti 2022.

Such tree masses allow a shaded area equal to 30 percent of the open spaces, the latter consisting mainly of lawn areas (with predominance of herbaceous species such as 'Poa pratensis' and 'Festuca arundinacea') and land with 'arable' urban land use (Figure 3).

Figure 3. *Vegetation Census of the San Basilio PdZ in the Fall-Winter Period with Quantification of Key Environmental Parameters*

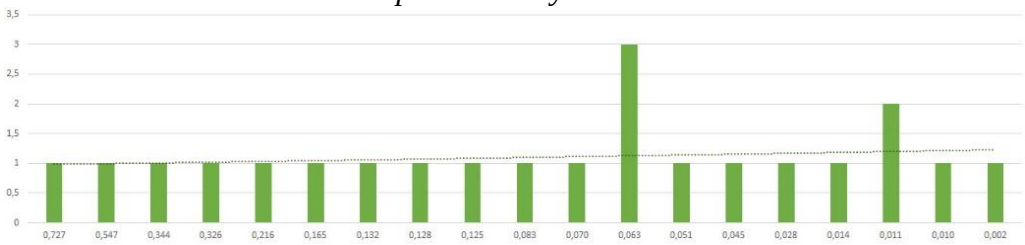


Source: Giampaoletti 2022.

The species surveyed were predominantly Alloctonous (64%, 14 species) with low environmental sustainability, according to the Status of Exoticity mainly Indigenous (36%, 8 species), followed by Invasive Neophytes (18%, 4 species), Naturalized Neophytes (18%, 4 species), Random Neophytes (14%, 3 species), Naturalized Neophytes (9%, 2 species) and Random Archaeophytes (5%, 1 species). The total CO_2 uptake capacity from the atmosphere of the present tree masses and flush green spaces was estimated to be 360,577 $KgCO_2eq$/year. This absorption capacity results overall of Medium-High and High level; the species with the highest potential for carbon absorption and storage turns out to be 'Pinus pinea', a naturalized Archeophyte species and not spontaneous in the Metropolitan City of Rome Capital.

The TS1 applied for the surveyed species (Figure 7) shows a homogeneous distribution frequency with the maximum value of 0.727, a minimum value of 0.002 and an average value of 0.163. The TSm of the species analyzed and surveyed turns out to be 0.147, a value 43% higher than the average found for the tree and shrub census of species present in the Metropolitan City of Rome Capital.

Figure 4. *Distribution Frequency Graph of the Taxonomic Stocking Index (TS) Related to the Tree and Shrub Species Surveyed in the St. Basil PDZ*



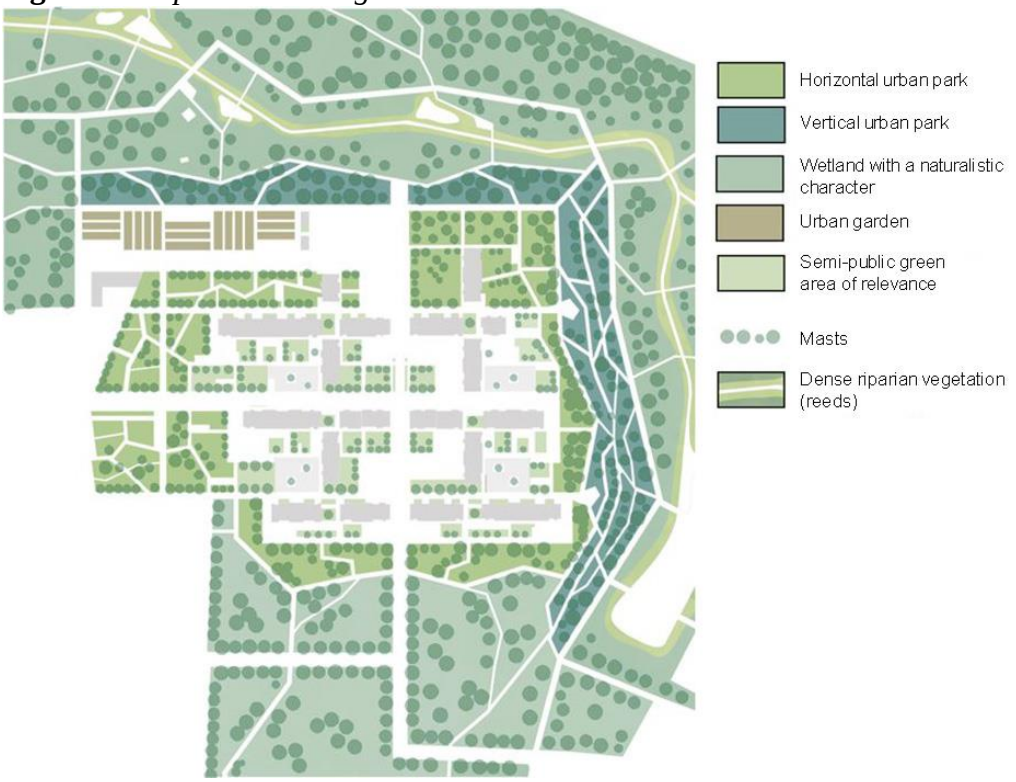
Source: Giampaoletti 2022.

Results

Proposed Greening Intervention aimed at Carbon Removal and Increasing Environmental Quality

The proposed greening intervention for the entire San Basilio PdZ is based on the one hand, on a targeted and design-oriented (and simulated) increase in the existing, native, and high-environmental-mitigating vegetation masses, eliminating potentially non-native and invasive species, and, on the other hand, on the recovery, re-functionalization and enhancement of open spaces, with elevation of their overall environmental quality (Figure 5).

Figure 5. *Proposed Greening Intervention in the San Basilio PDZ*



Source: Giampaoletti 2022.

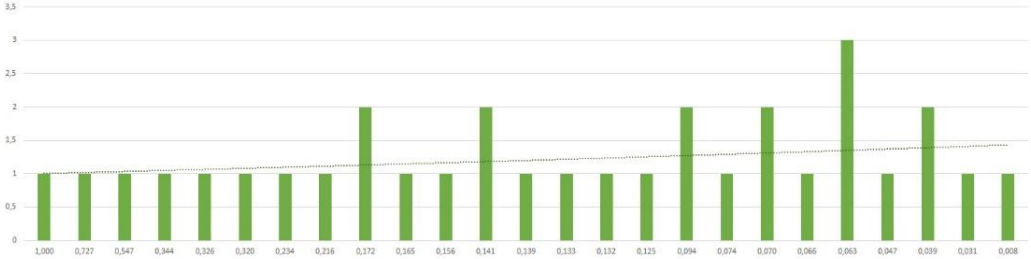
The hypothesized scenario included the enhancement of resilient native species including 'Fagus sylvatica', 'Olea europaea', 'Pinus pinea' and the introduction of an additional 5 sustainable vegetation species with high environmental mitigation capacities in carbon uptake and storage from the atmosphere such as 'Pinus halepensis', 'Populus tremula', 'Quercus pubescens', 'Quercus suber'. In addition, the eradication of no. 128 individuals including invasive and infesting trees and shrubs such as, for example, 'Acacia dealbata', 'Ailanthus altissima', 'Junglas regia', 'Robinia pseudoacacia' as well as shrub species, mainly 'Pinus pinea', too close to the building structures, which created problems of natural ventilation and shading in the inspections that took place in the summer and winter periods, also with obvious problems of structural hazard, detected through the VTA (Visual Tree Assessment) technique. The more than 70 shrubby individuals of 'Laurus nobilis' defining the 200 meters of hedges and roadside borders in the intervention area were also preserved.

A total of 587 new tree and shrub individuals allocated in the degraded, recovered and upgraded areas were introduced (32 genera for a total share of 961 individuals) for a total carbon uptake of 506,816 $KgCO_2eq$/year. The 32 species present in this redevelopment scenario are almost exclusively predominantly Autochthonous (94%, 30 species) with a significant increase in environmental sustainability demonstrated, according to Exoticity Status by the establishment of mainly Indigenous species (91%, 29 species), followed by Random Neophytes (3%, 1 species), Naturalized Neophytes (3%, 1 species) and Naturalized Archaeophytes (3%, 1 species).

Discussion

The adoption of the strategies described above has defined design lines that can be verified by quantifying the effects they introduce in the area under experimentation. In detail, these green solutions concerned the increase of the tree and shrub heritage through the enhancement of existing sustainable species and the introduction of new native, high environmental sustainability and spontaneous species of the metropolitan territory of Roma Capitale, the increase of wetlands and the enhancement of open spaces. The capacity of CO_2 uptake from the atmosphere exerted by the area's tree stock, as a result of the planned and simulated operations of introduction and removal of certain species, turns out to be of High level overall, thus improving the uptake performance compared to the state of affairs. It should be noted that the species with the highest potential for carbon uptake and storage turns out to be 'Pinus halepensis,' an entity indigenous and spontaneous in the Metropolitan City of Rome Capital and with a high capacity for environmental mitigation, which not coincidentally was among the species introduced in the urban reforestation project in the area. The TS applied for the species present in this scenario (Figure 6) presents a homogeneous distribution frequency with the maximum value equal to 1, a minimum value equal to 0.008 and a TSm equal to 0.188, increasing by 28%, the environmental capacity of carbon uptake in relation to exotic status, compared to the state of affairs.

Figure 6. *Distribution Frequency Graph of Taxonomic Stocking Index (TS) Related to Tree and Shrub Species in the Proposed Urban Regeneration*



Source: Giampaoletti 2022.

The mix of these environmental strategies results in an overall increase in CO_2 absorption of +183% (1,068,380 $KgCO_2eq$/year) compared to the state of affairs, resulting from the complex of design actions that have produced an increase - not only of a quantitative but above all of a qualitative nature - of 30% (40,121 sq. m.) of green spaces, among which must also be considered those represented by the introduction of 'green roofs' and 'brown roofs' (1,152 sq. m.), resulting in the recovery of previously degraded soils. This methodological approach is also still underway in another public housing area falling within the San Basilio neighborhood built in the 1950s, specifically between Loreto street and Casale di San Basilio street (Figure 7), finding, on a preliminary basis, similar values to the present research.

Figure 7. *Preliminary Design Proposal for Environmental Mitigation in the Nearby Intervention Area between Loreto Street and Casale di San Basilio Street*

Source: Giampaoletti 2022.

Conclusions

The research highlighted important strategies in the field of green solutions aimed at increasing environmental well-being in a peri-urban neighborhood of the Metropolitan City of Rome Capital, proposing targeted intervention scenarios in order to increase carbon storage capacity from the atmosphere through urban reforestation actions with native species and high environmental mitigation capacity. The perspectives for research, based on the development of calculation and verification methodologies according to the establishment of solid and scientifically reliable databases, calibrated on the characters of the national context and in particular on those of areas constituting urban and peri-urban neighborhoods of cities, may concern the increase of census tree and shrub species, progressively expanding the scope of application on the entire national territory (and theoretically, in a perspective of growth, on the dimension at least European, not to say worldwide), in order to provide the scientific community and the actors in the process - such as those in the public and private sectors hopefully favorable to the increase of knowledge towards such strategies and practices, as in the case of the San Basilio PdZ presented as an example in this contribution - with a curated and detailed model for calculating the really achievable carbon uptake, aimed at favoring, in the processes of redevelopment of open spaces, the introduction of native and native individuals of the place, disincentivizing alien species, often highly invasive (European Commission 2021).

The increase in the number of tree and shrub species surveyed and

implemented in the database presented will also help to refine and improve the 'taxonomic stocking index' (TS) as it is applicable in every national and, in perspective, European area (even the globe) and comparable across multiple areas, even distant from each other, through the use of the 'average taxonomic stocking index' (TSm). The latter also could find a potential relationship with the number of tree and shrub essences that make up an area of intervention such as may be a neighborhood or district of a city; in the proposed case, falling within the Metropolitan City of Rome Capital, it has not been possible to carry out this application in an integral manner over the entire metropolitan territory since there is no complete and detailed census of the masses of trees and shrubs present to date, but only that of the shrub essences present in the parks and green spaces managed by the Municipal Administration, thus constituting a limitation to the present research.

Finally, further future research perspectives may concern the comparison between neighborhoods and districts of the same city or of European and world cities aimed at refining the 'taxonomic mean stocking index' (TSm) by investigating the latter's potential relationships with environmental certifications and energy standards often present in urban regeneration interventions, as present in the Aspern Seestadt eco-district in Vienna, Austria or the Clichy Batignolles eco-district in Paris, France, with a view to quantifying reductions in carbon emissions into the atmosphere.

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Notes

1) Qualitative-quantitative index based on the mathematical relationship between a species' ability to absorb carbon from the atmosphere (C) and exotic status (E):

$$TS = \frac{C}{E}$$

With index tending to 1, the choice of tree species has greater sustainability in terms of its ability to absorb carbon from the atmosphere in relation to its exotic status (E); for values tending to 0, the choice is not sustainable.

2) No. 5 new tree and shrub species were introduced that were not surveyed in the area being redeveloped but proposed in the urban regeneration project because they are native, sustainable, and spontaneous in the Metropolitan City of Rome Capital and have high CO_2 absorption and storage capacities.
3) The VTA method, evaluated on a biomechanical basis, consists of visual recognition of characteristic external signs and symptoms of structural or plant hazard warnings, thus enabling quick identification of tree subjects at static risk.