**Università degli Studi di Milano**

**Ph.D. in Agriculture, Environment and Bioenergy**

**XXXIII Cycle**


# ECOSYSTEM SERVICES: PROVISION, ASSESSMENT AND QUANTIFICATION

**How to council sustainable food provision, territorial planning, urban development and natural capital? Case studies and experiences for a sustainable future**


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**Acknowledgements**

First and foremost, I would like to thank Prof. Stefano Bocchi – my tutor – for his continuous support, his guidance and advice during the Ph.D. period. His academic depth and his personal attitude have been a great example.

I would also like to thank all the people that helped me during the development of my research, and in particular Dr. Roberto Spigarolo, for the precious time, suggestions and the shared activities during OpenAgri project, and Prof. Vittorio Ingegnoli, for the introduction to Planetary Health concepts.

I am sincerely grateful to Dr. Valentina Vaglia, for the great contribution in many research aspects and for all the shared moments.

I am also thankful to Dr. Francesco Fava, for his mentoring during the Ph.D. period and for the insightful comments and advice.

The last three years have been really challenging, since I had to face the most unexpected event: illness. I am more than thankful to everyone who supported me, for the great care, attention and endless support showed during my recovery.

In the light of this, I am even more grateful to everyone's support during the most difficult time.

Last but not least, I am very thankful to my family, which has always supported me during the last three years, my friends, and to Melania, for her unvaluable encouragement and endless patience. Without their support and help, especially in difficult times, it would not be possible to complete this dissertation.

**Abstract**

The doctoral dissertation represents an investigation into the topic of Ecosystem Services and the related challenges that our society has to face, such as the integration between environmental conservation, sustainable food provision, socio-economic development and the need for improving quality of life. In particular, the dissertation proposes a set of case studies thanks to which it is possible to evaluate and assess the provision of Ecosystem Services in different contexts and at different spatial scale, both in agricultural and urbanized areas, therefore showing, from various point of views, the implementations of Ecosystem Services driven policies and approaches. Through the exploration of different environments, the interactions between new forms of agriculture (e.g., agroecology and agroforestry), territorial planning and environmental benefits can be observed, explaining dynamics and opportunities deriving from the application of combined frameworks capable to council both theoretical and practical aspects. The adoption of these frameworks, as well as the related analytical research methodologies, allows, on the one hand, a deeper understanding of the "state-of-art" scenario among Ecosystem Services concept and, on the other, provides specific insights for the transition to a more sustainable development and clear perspectives about the needed future research directions.

# Summary

**Acronyms and abbreviations**

AF= Agroforestry

CAP= Common Agricultural Policy

CICES= Common International Classification of Ecosystem Services

EBS= Ecosystem Based Solutions

EDS= Ecosystem Disservices

ES= Ecosystem Services

LAS= Local Agri-Food System

MEA= Millennium Ecosystem Assessment

NBS= Nature Based Solutions

PB= Planetary Boundaries

PES=Payment for Ecosystem Services

PUA= Peri-Urban Agriculture

SDGs= Sustainable Development Goals

TEEB= The Economics of Ecosystems and Biodiversity

UA= Urban Agriculture

UF= Urban Forestry

# 1. Introduction

## 1.1 Research context

### 1.1.1 Ecosystem services concept and definition

It is clear that climatic and environmental conditions that support human life are changing (1), resulting in an overall degrading of world natural capital, definable as the world's stocks of natural assets which include geology, soil, air, water and all living things (2). This means that not only human species is affected by these changes, but most of other species too, as well as the complex relations and links between them (3). This relation web forms ecosystems, which provide Ecosystem Services (ES) to the humankind. Overall, we can define ES as the benefits humans receive from the surroundings ecosystems (3). This concept – and the related considerations on ecosystem degradation – has arisen on the international debate since the 1970s. A key milestone in developing awareness on environmental problems was represented by Stockholm Conference on the human environment (1972), upon initiative of the United Nations Organization (UN), where the Declaration of the human environment was approved (4). In the following decades, several programs and frameworks were put in place, as the Rio de Janeiro Conference (1992). At the same time, academics and researchers began to investigate the link between human health and natural systems. In particular, the work of DeGroot (1992), Costanza (1997) and Daily (1997) marked the point, since they introduced ES concept and their quantification (5,6,7).

From there on, ecosystem analysis and ES assessment acquired importance, since the growing awareness on planet boundaries (8) and the deeper understanding, in ecological terms, of the complicated relationship between wealth, human well-being, biodiversity and ecosystems, with their related services. Millennium Ecosystem Assessment (MEA) aimed at analysing, through solid multidisciplinary scientific bases, the evolution of the planet's ecosystems in the light of human activities, identifying intervention strategies for sustainable development. MEA defines ES as "benefits that humans derive from ecosystems" (3): this definition summarises more articulated definitions, as the ones previously introduced by Daily (7), where ecosystem services are "the conditions and processes through which natural ecosystems, and the species that make them up, sustain, and fulfil human life" and Costanza (6), which defines ES as "benefits that human populations derive directly or indirectly from the functions of ecosystems". ES maintain biodiversity and the production of goods such as food, fodder, timber, fuels and industrial and para-pharmaceutical products.

Moreover, MEA introduces four different ES categories (Fig.1): supporting, provisioning, regulating and cultural ES. Where:

- i) supporting ES are base services necessary to provide all other ES. This category mainly embraces ES that have indirect impact on human life and occur over a long time period (e.g., soil formation);
- ii) provisioning ES are the ones that provide material goods, including food and fibres;
- iii) regulating ES grant benefits occurring from environmental processes regulation, such as climate and water regulation;
- iv) cultural ES offer intangible benefits, contributing to the maintenance of human health through spiritual enrichment, reflection, cognitive development and aesthetic and recreational experiences.

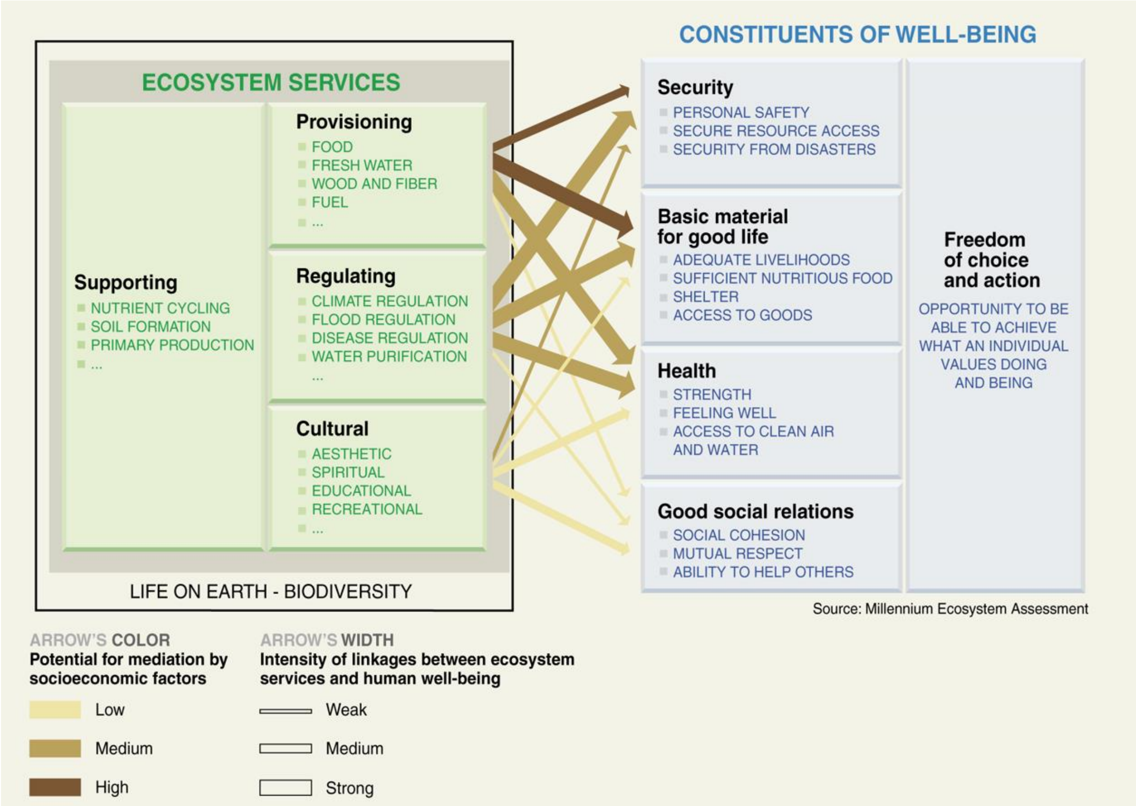


**Fig. 1** Ecosystem services and their classification. Source: Millennium Ecosystem Assessment, 2005.

Other types of ES classification have been developed. CICES (Common International Classification of Ecosystem Services) organizes ES in a hierarchical structure (9) (Fig. 2):

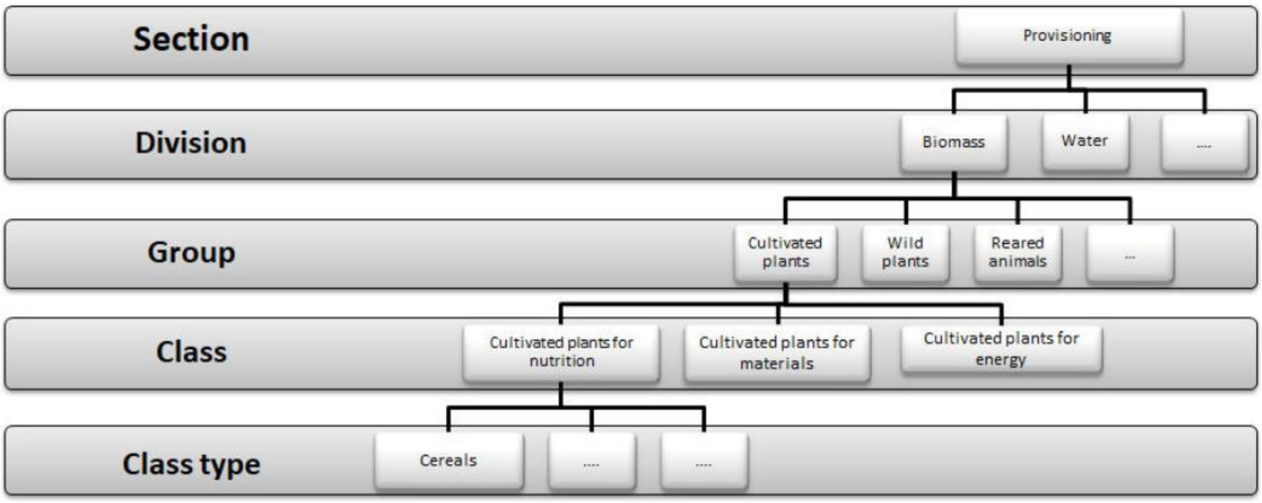


**Fig.2** Cices hierarchical structure to classify ES. Source: Haines-Young R., Potschin-Young M.B., 2018, Revision of the Common International Classification for Ecosystem Services (CICES V5.1): A Policy Brief

With three main sections, that correspond to the ES macro-categories; divisions, or the main outputs; groups, which determine the biological and material processes; and classes, which indicate individual entities, provided with units of measurement and indicators to quantify ES. CICES has been widely adopted, and recently has been chosen as main framework by the European Environmental Agency to develop ES indicators within the EU on Mapping and Assessment of Ecosystems and their Services (MAES) program (10).

An alternative classification has been proposed by TEEB (The Economics of Ecosystems and Biodiversity) (11), which is focused on the relationship between natural capital and socio-economic themes, with the aim of letting emerge the economic importance of nature in our lives.

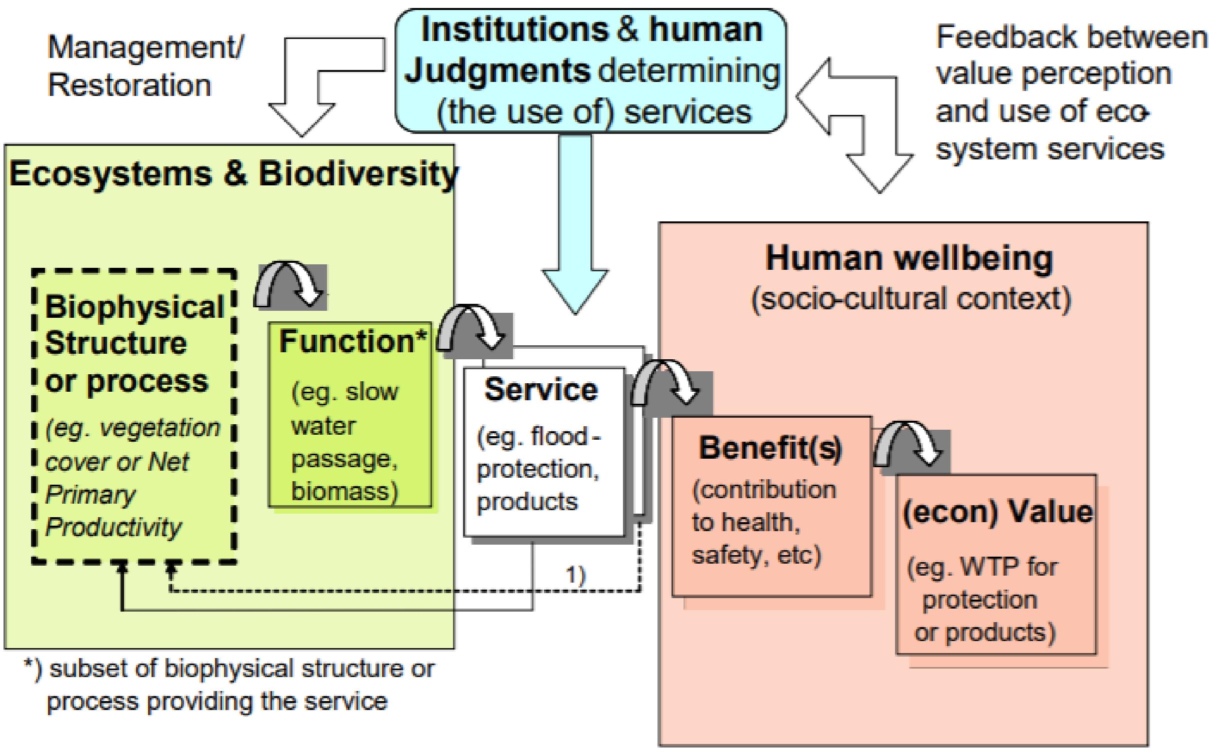


**Fig. 3** TEEB framework to define ES value. Natural benefits can be valued thanks to different indicators (economic, socio-cultural and biophysical). Source: De Groot et al., 2010, Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation, TEEB.

With the definitions of ES, the concept of ecosystem disservices (EDS) raised too. EDS can be defined as functions or properties of ecosystems that cause effects that are perceived as harmful, unpleasant or unwanted (12). EDS can result from natural or relatively undisturbed ecosystems or they can be effects or side-effects of deliberate manipulation of ecosystems. EDS results in damages to human economic activities (e.g., loss during agricultural processes due to pests), to human health (e.g., pollens causing allergic reaction) and even to human psychology (e.g., fear perception in urban parks during night-time) (13). EDS concept is debated in academic world: indeed, as stated by recent researchers, EDS frameworks may lead to misjudgements on nature's role (14), downsizing environmental contribution to human well-being (15). It is more interesting to see ES and EDS as linked entities that depend on human activities: e.g., agricultural processes and management approaches can lead to various levels of ES and EDS (16). Therefore, modern agriculture must find a positive trade-off between providing ES, while reducing EDS – e.g., how to balance chemical inputs with soil degradation?

However, today, it is still missing an integrative and policy-relevant framework to evaluate the link between ES and EDS, as well as a communication strategy addressed to the public opinion, which may face difficulties in understanding EDS concept and its implication without associating nature to negative impacts. Moreover, ES and EDS classification has led to the idea of quantifying their value, in economic terms too. However, this topic is debated, as various researchers (17) consider the economic quantification inappropriate, since the difficulties of monetising uncertain entities, such as people perception of natural beauty, usefulness or health - all elements that are not always quantifiable at a monetary level.

Anyhow, today, ES concept is widespread and has been integrated in the principal international strategies and regulations.

The 2030 Agenda for Sustainable Development, agreed by the 193 States Members of the UN, sets an ambitious framework of universal and indivisible goals and targets to address a range of global societal challenges. Biodiversity and ecosystems feature prominently across many of the Sustainable Development Goals (SDGs) and associated targets. They contribute directly to human well-being and development priorities since nearly half of the human population is directly dependent on natural resources for its livelihood, and many of the most vulnerable people depend directly on biodiversity to fulfil their daily subsistence needs (18). Therefore, SDGs pursuit and implementation are possible only if ecosystem are protected and ES provision is guaranteed.

European directives deem as a priority ES provisions, too. Latest documents on environmental topics – e.g., Farm To Fork strategy (19) and EU biodiversity strategy for 2030 (20) – highlight the link between a sustainable socio-economic development and ES provision, especially in urban and peri-urban area, where population keeps on concentrating (21), resulting in heavy degradation of ecosystem and in a poor life quality of inhabitants.

### 1.1.2 Ecosystem services, human pressure and related risks

Therefore, it is stated that human well-being is strictly related to ecosystems and their benefits. This relationship is bijective, since if ecosystems influence human well-being, human activities affect ecosystem balance too. Humankind is an integrated part of ecosystems, actively contributing and shaping the processes that take place in natural environments, which are dynamic contexts. Indeed, nature is not a static entity, but can be seen as a delicate balance between several parts. Within this balance, some factors can lead to modifications in ecosystems – and therefore in ES provision. These factors, known as drivers, may be classified as endogenous, if they can be influenced by decision-makers, or as exogenous, if out of decision-making process (23). Drivers may then be classified as direct or indirect: the first one act on ecosystem processes (e.g., air and water pollutants); while the latter indirectly alter ecosystem acting on direct drivers: demographic changes, economic development, technological improvements, cultural habits and religious sphere and their related issues can cause pressure on ecosystem.

One of the main pressure drivers is represented by the continuous growth of world population and its concentration in urban agglomerates. These phenomena lead to an uninterrupted and uncontrolled soil loss, due to urban expansion (23). MEA highlights that European natural capital has undergone the greatest fragmentation by man: only 1-3% of forests in Western Europe can be defined as "undisturbed by human presence" (24). Moreover, socio-economic and technological improvements cause a rise in consumer expectations and choices (25) and a growing desire to achieve and maintain a high quality of lifestyle as typical of developed countries. These trends are contributing to an overexploitation of natural resources: indeed, our predominant economy models, developed from the early stages of industrialization, assumes the unlimited availability of resources, a concept that proved wrong with the emergence of the problem of their scarcity. An unsustainable use – resulting in an abuse – of natural capital compromises the effective ES provision (26). To show this concept, a useful indicator to represent environmental exploitation is the ecological footprint (Figure 4), which demonstrates the evolution over the last fifty years of the biocapacity of ecological system, thus their ability to provide resources.

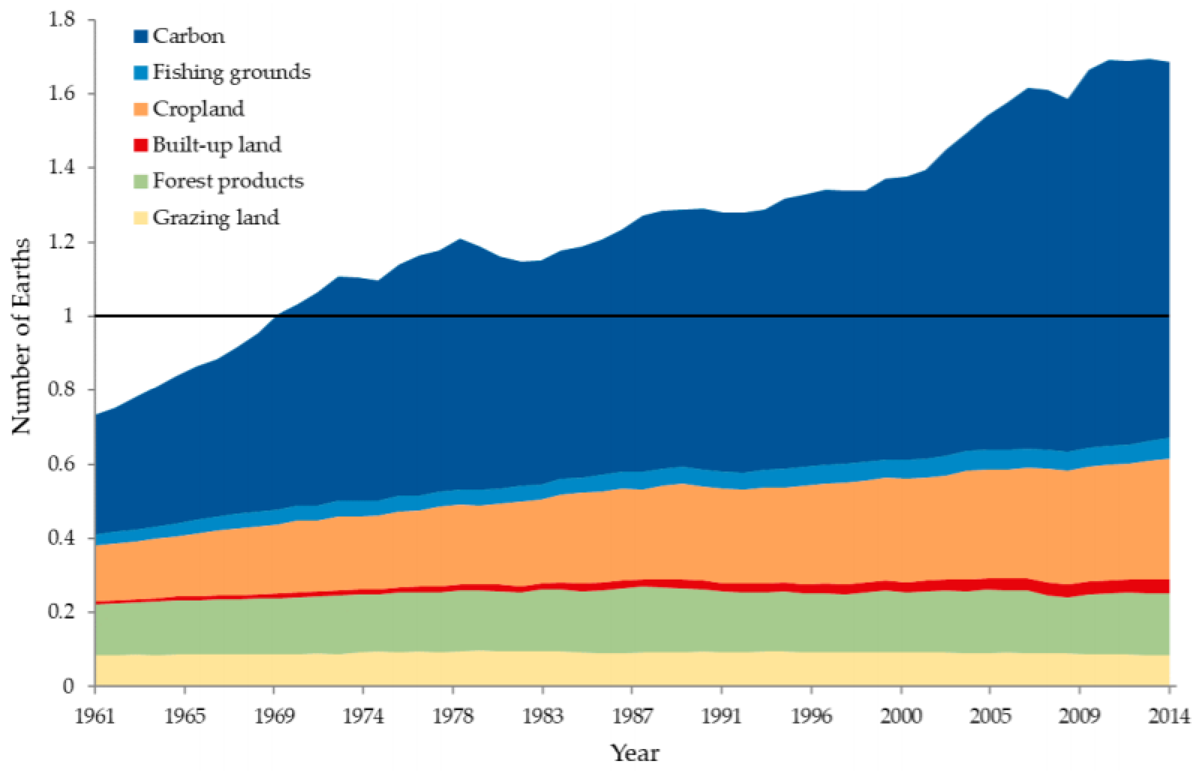


**Fig. 4** World ecological footprint type from 1961 to 2014. Ecological footprint values are related to the "Number of Earths" indicator that divides the ecological footprint by the global biocapacity available to each person in the world in 2014. The overtaking of 1 earth shows the overshoot trend. Source: 26. Lin D., Hanscom L., Murthy A., Galli A., Evans M., Neill E., Mancini M.S., Martindill J., Medouar F.Z., Huang S., Wackernagel M., Ecological Footprint Accounting for Countries: Updates and Results of the National Footprint Accounts, 2012–2018, Resources 2018, 7, 58; doi:10.3390/resources7030058

To demonstrate overshoot concept, in 2009 Rockström (1) identified nine processes that regulate the stability and resilience of the Earth system, and proposed quantitative planetary boundaries (PB) within which humanity can continue to develop. Crossing one or more PB may trigger non-linear, abrupt environmental change within continental- to planetary-scale systems. Nine PB were proposed, and out of these, seven were quantified: climate change ($CO_2$ concentration in the atmosphere <350 ppm and/or a maximum change of +1 W m-2 in radiative forcing); ocean acidification (mean surface seawater saturation state with respect to aragonite ≥ 80% of pre-industrial levels); stratospheric ozone (<5% reduction in $O_3$ concentration from pre-industrial level of 290 Dobson Units); biogeochemical nitrogen (N) cycle (limit industrial and agricultural fixation of $N_2$ to 35 Tg N yr-1) and phosphorus (P) cycle (annual P inflow to oceans not to exceed 10 times the natural background weathering of P); global freshwater use (<4000 $km^3$ yr-1 of consumptive use of runoff resources); land system change (<15% of the ice-free land surface under cropland); and the rate at which biological diversity is lost (annual rate of <10 extinctions per million species). Stockholm Resilience Center estimated that humanity has already transgressed three PB (Fig.5):

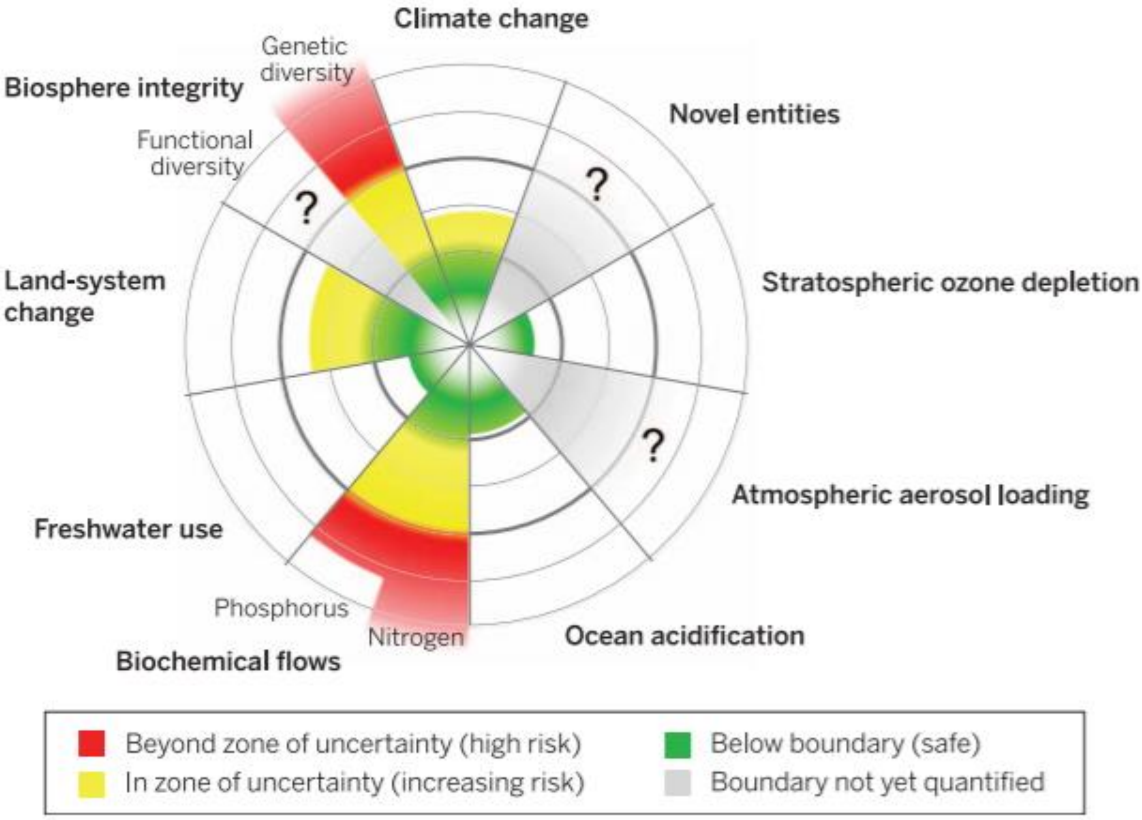


**Fig. 5** The current status of the control variables for seven of the nine planetary boundaries. Source: Steffen and others, 16 January 2015, Science

### 1.1.3 Agriculture and ES

For the past twenty years, agriculture has covered more than a third of total land area (27) and represents humankind's largest modified ecosystem (28), forming the agroecosystems, which are managed by humans to maximize productions of food, fibres and other goods. Therefore, original and main scope of agricultural activity is to supply the so-called provisioning ES (16). However, agriculture depends too on other ecosystem dynamics (e.g., pollinators activity, soil formation) and thus it both provides and relies on ES to complete its original purpose. Agriculture causes and suffers of Ecosystem Disservices too. Indeed, food production may decrease due to competition for water, or the presence of herbivory (28), while it generates different EDS level depending on management and environmental factors. The balance between ES and EDS provision is a complex dynamic entity where human activity plays a crucial role.

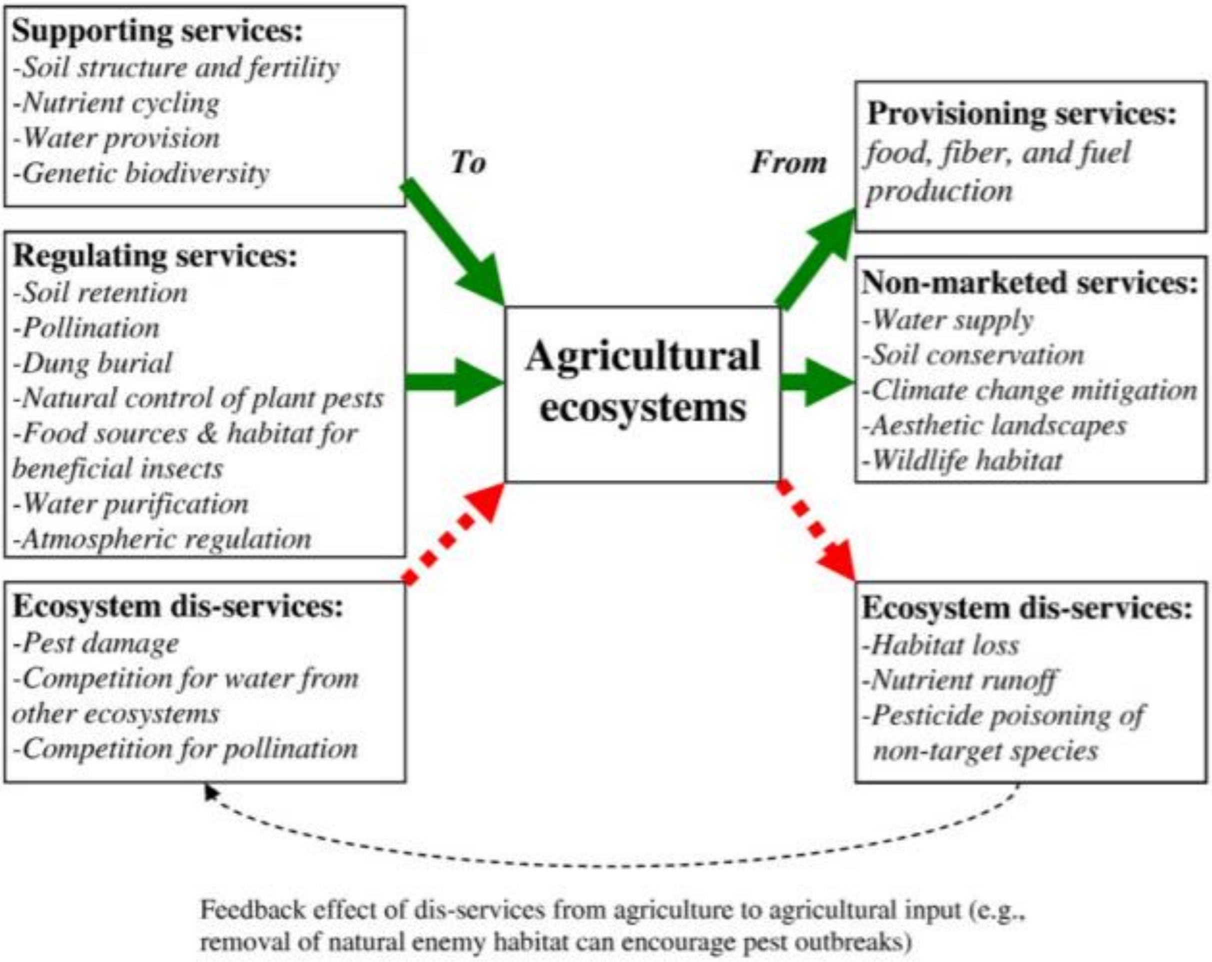


**Fig. 6** Ecosystem services and disservices to and from agriculture system. Solid arrows indicate services, while dashed arrows indicate disservices. Source: Zang W., Ricketts T.H., Kremen C., Carney K., Swinton S.M., Ecosystem services and dis-services to agriculture, Ecological Economics, 64, 253–260, 2007

The role of agriculture in providing food supply has increased during the so-called Green Revolution, when, in few decades, agricultural productivity hugely arose, allowing a wider food security, but causing too environmental issues. Due to this negative impact, agriculture is often considered anathema to conservation (16). However, a proper management can council food provision and many of the negative impacts of agriculture. In the last decades, many researchers and academics proposed alternative way of producing foods, introducing and spreading new systemic visions capable to consider the overall agroecosystem and legitimate farmers' requests.

Among others, agroecology approach has gained increasing attention on the international scenario. Agroecology uses ecological concepts and principles for the design and management of sustainable agroecosystems where external inputs are replaced by natural processes such as natural soil fertility and biological control (29). Therefore, agroecology flanks food production with environmental conservation and input reductions, to assure both food security and fair economic incomes to small-holder farmers. Therefore, we may see agroecology as a form to expand agriculture ES provision, while reducing EDS. Agroecology combines scientific and practical approach to sustainable agriculture (30). Indeed, it fosters the study of ecological processes in farming systems as well as the practice of applying ecological concepts and principles to the design and management of sustainable agroecosystems. In these terms, it minimises or precludes the use of fossil fuels, chemical inputs, and large-scale monocropping. Instead, agroecology promotes a systemic approach and the multifunctional dimensions of agriculture: food and fibres production, food security, health benefits, job security, social and economic justice, culture, and community resilience (31). This approach is returning a net provision of ES, such as erosion control, carbon sequestration, pollinator protection, biodiversity conservation, water and nutrient cycling (nothing wasted, everything transformed), air and water quality (32; 33). Agroecology is not a one-size-fits-all solution, but it should be calibrated according to local socio-economic and environmental conditions. A wider spread of agroecology may assure a fairer access to a safe and nutritious food, since if Green Revolution has allowed to grow enough food, a large portion of world's inhabitants still challenge to reach food security and safety. Moreover, the mainstream global agriculture has contributed to the crossing of PB and misuse of natural resources (Tab.1).

| **Global process (defined by Steffen et al., 2015)** | **Proposed boundary and current status (orange=high risk; yellow= increasing risk; green=safe)** | **Agriculture's impact** | **Benefits of an Agroecological approach** |
|---|---|---|---|
| **Climate change** Global temperature has risen by nearly 0.7°C since 1950, mostly due to $CO_2$ emissions from fossil fuel use. | **Boundary:** atmospheric concentration no higher than 350 ppm$CO_2$ **Current:** 400 ppm $CO_2$ ***and rising.*** | Agriculture is responsible for 30 % of greenhouses gases, making it the single largest contributor to climate change (Vermeulen et al., 2012). | Fossil energy inputs can be up to 30% lower than conventional crops. Agroecological systems (use of perennial crops, intercropping and agroforestry systems) can contribute to decrease carbon emission. |
| **Loss of biosphere integrity** Wild animal populations have roughly halved since 1970 and ecosystems worldwide have been impacted by human activities. | **Boundary:** no more than 10 extinctions per million species per year. **Current:** ~1000 E/MSY ***and rising*** (plus regionally determined boundaries for ecosystem function). | Agriculture remains the largest driver of genetic erosion. Since the 1900s, 75 % of plant genetic diversity has been lost as many farmers have switched to genetically uniform, high-yielding varieties (FAO, 1999). | Agroecology fosters diversity of crops, varieties, farming methods and ecosystem services. Many studies have shown that different applied agroecological production systems facilitate for higher biodiversity in and around fields. |
| Changes to biogeochemical flows – **Nitrogen**. Rises in N emissions cause severe air pollution and affect climate through release of nitrous gas. | **Boundary:** no more than 62 million tons N applied to land per year **Current:** ~150 Mt per year ***and rising***. | Synthetic nitrogen fertilizers have helped to increase yields, but excessive use and/or inappropriate application has also caused significant eutrophication. | Intercropping and ground cover species including N-fixing legumes, together with composting and recycling of manure minimises the need for synthetic N fertilizers. |
| Changes to biogeochemical flows – **Phosphorous**. Rises in P emission cause nutrient pollution in lakes and seas. | **Boundary:** no more than 6,2 million tons P applied to land per year **Current:** ~14 M per year ***and rising*** | The application of industrially processed phosphorus fertilizers entails eutrophication problems. Natural resource used to make synthetic fertilizers are finite. | Composting and recycling of manure minimises the need for phosphorous fertilizers. Recirculation of urban waste can also add benefits by returning phosphate to the soil. |
| **Loss of stratospheric ozone,** allows more harmful UV light to reach Earth's surface. The minimum concentration has now been steady for ~15 years after phasing out of ozone depleting substances. | **Boundary:** no lower than 276 Dobson Units (DU) ozone (latitude-dependent) **Current:**28 DU ***and improving*** | Agriculture is the largest resource of nitrous oxide (laughing gas), producing two-thirds of total emissions. Nitrous oxide is the single biggest threat to the ozone layer since other damaging gases were restricted by the Montreal Protocol in 1987(UNEP, 2013). | Release of nitrous oxide from agroecological farming systems can be reduced through greater nitrogen circulation within the system and less total input of "new" nitrogen into the system. |
| **Ocean acidification** due to fossil fuel $CO_2$. Today's rate of ocean acidification is unprecedented in over 65 million years. Effects on marine life are already evident. | **Boundary:** ≥80 of pre- industrial ocean aragonite state at ration state **Current** ~84% of pre- industrial ocean aragonite saturation state | Agricultural production gives rise to massive emission of carbon dioxide which dissolve in water and produce carbonic acid, which then lowers the pH and cause severe impacts on life in the oceans. | Carbon dioxide is both a major greenhouse gas and the underlying cause of ocean acidification. Nitrogen contributes to ocean acidification. Le ss N input to the system result in less acidification. |
| **Freshwater** use (irrigation) impairs or even dries up rivers and aquifers, harming the environment and altering the hydrological cycle and climate. | **Boundary:** 4000 $km^3$ water use per year **Current** 260 $km^3$ per year River-basin boundaries are also defined. | Agriculture uses most of the planet's available fresh water; it accounts for 70% of the freshwater taken out of rivers, lakes, and aquifers (Postel et at., 1996). | Water-harvesting techniques and drip irrigation combined with higher levels of soil organic matter help to conserve water resources during drought years. |

| | | | |
|---|---|---|---|
| **Land use** change (forest conversion to croplands, roads and cities) | **Boundary:** no less than 75% of original natural forest cover<br>**Current:** 62% and shrinking | Agriculture has degraded 70% of grasslands, 50% of savannas, 45% of deciduous forests and more than a quarter of tropical forests. Land use change is driven by such things as population increase, dietary changes, changes in consumers habits, etc. (Foley and others, 2011) | Many fear that more land needs to be converted, but agroecologically managed crop yields on a per-hectare basis can equal or surpass those from conventional agriculture even doubling in many low yielding areas. |
| **Atmospheric aerosol** loading, Microparticles emitted into the air cause severe local pollution problems and global impacts on nature and climate. | Regionally determined, e.g., boundary for South Asia: Aerosol Optical Depth 0.25<br>Current: AOD 0.30 ('brown cloud') | A range of different airborne particles are released from agricultural production around the world, these include dust and soot. | Agroecological systems are often of a more perennial nature and do not include slash and burn agriculture. Systems with a soil cover are less susceptible to soil erosion. |
| Release of **novel entities** Synthetic substances – and even novel life-forms. | Multiple boundaries, yet to be quantified. | The use of synthetic pesticides, hormones and antibiotics as practised throughout the developing world, poses significant risks to human health and to biodiversity. | Biological control, combined with crop rotations and cover cropping, reduces pest problems, and consequently chemical pesticide use. |

**Tab. 1** Today's agriculture and its effect on PB. Globally, agriculture displaces natural ecosystems, uses too much fresh water, pollutes rivers and coastal seas, and releases greenhouse gases. Altogether, today's agriculture impacts all the nine planetary boundaries (updated by Steffen and others, 2015) that we should stay within to avoid large-scale and abrupt environmental change. In this context an agroecological approach holds much promise. Source: SIANI's Expert Group on Agriculture Transformation in Low-Income Countries. Authors: Fredrik Moberg (Editor), Karin Höök, Lennart Salomonsson, Kristina Mastroianni, Jakob Lundberg, Louise Karlberg, Gunnar Rundgren.

### 1.1.4 Payment for Ecosystem Services

Since agriculture is one the major driver in providing ES and EDS and since the balance between these two entities is highly dependent on human management, in the last decades many researchers proposed several frameworks aimed at economically incentive farmers to adopt more sustainable practices, to assure ES instead of EDS. Therefore, farmers can receive Payment for Ecosystem Services (PES), based on positive environmental externalities; while MES – Markets for Ecosystem Services – scheme is based on the opposite starting point: polluters pay to address negative environmental outcomes (34). The idea of linking ES – and more in general, natural capital – to a monetary value has caused diverse reactions between stake-holders and academics. Indeed, several academics retain as unethical to put a "price tag" on nature (34), since nature is separated entity from human economy and since it is at least difficult – if not impossible – to set the right economic values to an ecosystem and to the feelings that it generates on human minds.

Beside these criticisms, the idea of developing PES schemes is strictly linked to ES concept: indeed, Costanza – the economist which greatly contributed to the spread of ES concept – firstly conducted a global economic evaluation of ES provision. In this view, by assigning a monetary value, researchers and proposed frameworks – such as TEEB – aim at drawing attention to the invisibility of nature in the economic choices at international, national, and local policy-making. Therefore, attributing a value, this view hopes to change common perception of nature between public opinion and stake-holders, recognising this invisibility as a key driver of the ongoing depletion of ecosystems and biodiversity (35).

However, most of the PES-schemes developed are based on local solutions and contexts. One of the most notable examples of these solutions regards New York City's (NYC) watershed. While most of U.S. cities have chosen to filter their water, NYC has adopted a different solution: instead of building filtration plants, NYC has chosen to protect watersheds thus having water sources with low percentage of pollutants. This is possible thanks to a specific watershed protection plan – still ongoing since 1997, that makes NYC as one of the first PES players. NYC acts as the buyer of the ES - water quality - from many surrounding territories – 70 towns and villages in the Catskill-Delaware watershed – which provides 90% of NYC's drinking water. Thanks to this PES agreement, NYC invested $1.5 billion in the first 10 years to restore and protect the watershed and to improve the local economies and quality of life of watershed residents (36).

Despite successful spot cases, it is still missing a global framework capable to implement a PES scheme. At continental scale, European Union (EU), within the Common Agricultural Policy (CAP), is undergoing a long path to increase sustainability in agriculture and linking payments to environmental compliance. Greening – or sustainable land use – has been already introduced, allocating 30% of the economic support to the respect of three main actions: crop diversification; permanent grassland and the assignment of 5% of the farmland to biodiversity protection. However, since the ambitious goals fixed by EU (19) and the will of becoming the first carbon neutral continent within 2050, a sharper action is needed. In this sense, the introduction of Eco-Schemes and the next CAP reform, with the definition of Agri-Environmental-Climate Measures (AECM), seem to introduce a PES approach, fostering farmers to an environmental transition (37).

### 1.2 Research questions and goals

Despite the centrality that ES topics cover in the academic panorama, there are several aspects to be investigated. Indeed, even if there are several frameworks and tools available, it is missing an accepted and uniform methodology to quantify and assess ES levels. Most of available researches are focused on ES provision in given environments, analysing limited ES and not the overall provision. Moreover, ES provision vary at different contexts and at different spatial scale and configuration, therefore assessment and quantification should be able to adapt to changing conditions.

Starting from these assumptions, the PhD research activity has been focused on assessing, quantifying and foreseeing ES levels in different conditions, thanks to the analysis of notable case studies. The fundamental research questions identified at the beginning of the PhD period have been, firstly, the need of understanding how ES concept can vary, and secondary, how it could be possible to integrate and council human activities – not only agriculture, but territorial planning too – and ES improvements.

The doctoral dissertation is organised in different chapters. Accordingly to PhD school guidelines, the thesis is structured as article collection model. This means that it should be possible to read each chapter individually and that each chapter should be constructed according to the rules of a scientific article (e.g., introduction, methodology, results, discussions, conclusions). Therefore, in this thesis, each chapter represents a published paper or an under review article or a draft ready to the submission. Every chapter was developed during the doctoral period and it is focused on different and peculiar point of view regarding ES. Since the topic is highly inter and transdisciplinary, the thesis takes into account a series of different case of studies, mainly in urban and peri-urban areas, with the final goal of assessing both environmental and socio-cultural requalification perspectives.

The first three chapters are related to a peri-urban area close to Milan, considered as interesting case study to evaluate ES under different points.

Therefore, chapter 2 is focused on regulating services provisions, thanks to the ongoing territorial requalification; chapter 3 analyses the link between ES provision and socio-economic issues typical of neglected peri-urban area; chapter 4 presents a sustainability assessment, completing the analysis of the area. This wide approach allowed to have a deep and articulated view on the potential ES level granted by the area, as well as a state-of-art of the current academic methodologies available to quantify ES.

In chapter 5, ES assessment is conducted in an urban area, thus changing both context and territorial scale. Moreover, working in urban environment allowed to underline the different ES granted by natural capital, with particular interest in socio-cultural ES.

Chapter 6 presents other academic activities carried out in the three-years period, in particular paper not directly linked to ES analysis and several poster presentations at conferences.

Finally, chapter 7 draws the future path to further develop the proposed research line.

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# 2.ES provision in peri-urban area: regulating ES and territorial planning analysis

**Chapter Introduction**

The following chapter presents a research paper which is focused on the role of agroforestry and peri-urban agriculture in providing ES and on showing their potentiality, if involved in urban regeneration projects.

In particular, the research focus has been put on investigating the link between city development and peri-urban agriculture, with the involved ES provision and the environmental benefits, adding to this link the additional improvements granted by an agroforestry implementation.

Indeed, it is clear that land use changes have a great impact on ES provision, even more in urban and peri-urban environments, where ecosystems are particularly fragmented and their functions lost. Therefore, urban and peri-urban planning projects should consider not only economic impacts, but environmental effects too, in terms of systemic ES provision. To this end, urban and peri-urban agriculture may cover a major role in assuring sustainable development plans, while expanding available ES levels.

Furthermore, the research introduces a new and innovative prompt to regeneration processes by considering agroforestry as a key to boost and amplify ES provision, especially in areas where monocultures are still predominant and in contexts – such as peri-urban areas – where it is not considered as a practicable solution. Indeed, starting from a case study located in Milan, we show the several benefits that a peri-urban area may obtain if regenerating dismissed areas by implementing a peri-urban agriculture plan characterized by two possible alternative scenarios of agroforestry. Quantifying the reached ES level and their potential increase in thirty years, it emerges the dynamic interaction between different ES and the goodness of the proposed case study, which mixes agriculture, local markets and urban tissue regeneration.

The paper was submitted to the special issue "Urban Regeneration and Ecosystem Services Assessment" of Sustainability, a MDPI journal (Current Impact Factor: 2.576; 5-year Impact Factor: 2.798). After a major and a minor revision, the paper has been accepted and published.

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# Forecasting agroforestry ecosystem services provision in urban regeneration projects: experiences and perspectives from Milan

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**Abstract:** The expansion of urban agglomerates is causing significant environmental changes, while the demand and need for sustainability keep on growing. In this context, urban and peri-urban agriculture can play a crucial role, mainly if associated with an agroecological approach. Indeed, the extensive use of living fences and tree rows can improve the environmental quality, assuring ecosystem services (ES), developing a sustainable urban food system and increasing local productions and the related socio-economic improvements. This study aims to assess the benefits of an agroecological requalification of a dismissed peri-urban area in the South Milan Agricultural Regional Park (Italy), by evaluating two possible scenarios, both involving planting trees and shrubs in that area. The software I-Tree Eco simulates the ecosystem services provision of planting new hedgerows, evaluating the benefits over 30 years. The study underlines the difference between the two scenarios and how the planted area becomes an essential supplier of regulating ecosystem services for the neighbourhoods, increasing carbon storage and air pollution removal. Results were then analysed with a treemap, to better investigate and understand the relationship between the different ecosystem services, showing a notable increase in carbon sequestration at the end of the simulation (at year 30). The study shows a replicable example of a methodology and techniques that can be used to assess the ES in urban and peri-urban environments.

**Keywords:** Regulating Ecosystem Services; Peri-Urban Agriculture; Urban Sustainable Regeneration; Italy

### 2.1. Introduction

Due to the continuous urbanisation process, natural environments face severe consequences, such as biodiversity loss and general degradation of natural resources [1]. Agenda 2030 - a call to action for people, planet and prosperity – strongly underlines this trend, and it aims at pursuing 17 Sustainable Developments Goals and 169 targets within 15 years. These objectives seek to realise all human rights, balancing the three dimensions of sustainable development: the economic, social and environmental ones [2]. Recent decades experienced significant socio-economic changes, among all headed the increasing migration from rural to urban areas: since 2008, more than half of the world's population lives in cities, and by 2050, this percentage will grow up to 70 % [3], compared to only 13 % in 1900 [4].

Furthermore, urban areas use 75 % of the available natural resources, even if they occupy just 2 % of the Earth's surface [5]. This situation, which often took place without any regulatory plan – represents one of the main challenges to be addressed. [6]. Indeed, urban growth, especially in poor and developing countries, can cause overwhelming problems, such as the continuous increase of slum populations, inequalities, underemployment, pollution, traffic congestion, loss of urban green spaces, sprawl and high demand for services and infrastructures [7], which rarely can be satisfied. Therefore, to avoid these consequences and that urban development results in total degradation of natural resources and a complete loss of ecosystems, it appears that finding new ways for sustainable urban development is crucial to reach the goals defined in Agenda 2030 [2].

In this context, urban and peri-urban agriculture can help to improve liveability, by providing several ecosystem services (ES): urban food production contributes to the protection of natural resources and guarantees several ES (e.g., regulation of water cycles, soil formation and nutrient cycling) [8].

Starting from these assumptions, it becomes apparent that there is a compelling need for further research in order to enrich the knowledge and the available tools to better plan and manage territorial resources and improve sustainability.

#### 2.1.1. Urban regeneration projects, agroecology and agroforestry

Urban redevelopment projects can provide ES, resource efficiency and foster urban regeneration, particularly in underused areas [9]. The recovery of peri-urban areas is a typical example of good practices to implement [10] land resources in cities. In this context, agriculture redevelopment projects that might include green infrastructure (GI) allow the regeneration of peri-urban tissues, thanks to different new niches and ecosystems, suitable in urban and peri-urban environments [11]. The advantages for people living in GI cities are the deliveries of ES to residents, which can significantly improve the cities' quality of life [9].

As already affirmed in recent literature, several examples of municipalities aim to enhance the environmental and social quality of life and invest considerable financial capital in restoring or creating natural capital [12, 13, 14, 15, 16]. These examples survey the USA scenario, where municipal GI programs are focusing on pursuing the Clean Water Act standards [17] to reduce the rate and volume of stormwater run-off, thus improving water quality. Many urban areas are also suffering from the effects of poor air quality [18]. For example, considering the high levels of PM10 in the air, many researches underline the importance and the contribution of urban and peri-urban green areas to mitigate local air quality issues [19, 20, 21], mainly thanks to a tailored planning and management of urban and peri-urban forests. Urban and peri-urban forests' contribution to improving air quality has a role in Italian cities and peri-urban areas too [22], with a particular interest in $O_3$ and PM10.

Furthermore, agroforestry can provide multiple ES, acting simultaneously on carbon sequestration; soil enrichment; biodiversity conservation, air, and water quality improvement [23].

Our case study focuses on a peri-urban area at the fringe zone between Milan and the southern agricultural park (Italy). The urban sprawl phenomenon is typical in this context, and GI implementation foster the importance of permeable and vegetated soil surfaces for retaining, detaining, and infiltrating stormwater [24,

25]. The GI sites could include urban and peri-urban zones, natural and human-made habitats such as parks, green roofs, rain barrels, bioswales, street trees, permeable pavers, and community gardens [24, 25, 26].
This study associates GI sites' concept to peri-urban agriculture and agroforestry; and evaluates the contribution of a living network of trees and shrubs in the provision of ES, focusing on the regulating ones and particularly on C storage, C sequestration and other ES related to air quality.

Moreover, the research emphasises the concept of GI sites as structures able to provide benefits to urban, peri-urban greens spaces and natural areas, with a multifunctional role, mainly referring to the importance of interconnections between habitats [27]. In a neglected peri-urban area, GI – well planned, developed and maintained – can enhance the surrounding urban landscapes by providing natural capital [9, 28]. Cities worldwide have to face challenges related to the sustainability of their habitat for citizens because of the limited space availability and ecological preservation. For these reasons, we investigate GI's role that combines urban requalification with rational land use to enhance ES provision.

The innovative role that GI can also play in urban and peri-urban agriculture context is that they represent an essential instrument to increase biodiversity and complete the agricultural landscape, such as with the proper implementation of hedges and rows agroecological approach.

As it is known, agroecology comprehends the area of intersection of scientific disciplines based on ecology with technological innovations related to the agri-food system with social and political issues. It also covers the scientific concepts and principles applied to design and manage agri-food systems in a sustainable way. It offers the concept of the integrated study of the agri-food system's ecology, including ecological, economic and social dimensions [29].

Agroecology aims at maximising the ES offered by agricultural systems and agri-food supply chains, starting from production (e.g., food, fibres, materials, etc.) and regulation services, with particular reference to water (Figure 1). For these reasons, it is clear that an agroecological approach fits well with the needs of urban agglomerates, where the need for food goes hand in hand with the needs of ES.

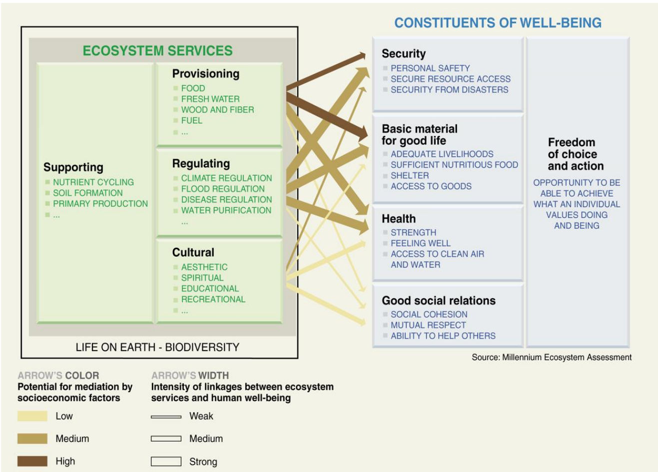


**Figure 1.** Ecosystem services and their classification – Millennium Ecosystem Assessment, 2005**.**

The peri-urban context within GI and the agroecological approaches are crucial for reaching a high ES provision level for the environments. One approach can also be agroforestry. It includes agricultural systems and techniques where herbaceous crops, woody species and-or animals are on the same unit of an agricultural surface according to a rational spatial distribution and a specific temporal sequence [30]. Therefore, it concerns agricultural land use by maintaining or introducing single trees or a mix of woody perennial species within cultivated fields to benefit from positive ecological interactions and practical economic implications.

Agroforestry systems contribute to the objectives identified in the Europe 2020 strategy for smart, sustainable and inclusive growth in the following ways: biomass production, improvement of the quality of the groundwater by slowing the leaching of nitrates, erosion control by providing permanent coverage of the soil, better adaptation and mitigation of the effects of climate change, prevention of fire damage in forests and limitation of irrigation use. FAO has highlighted Agroforestry's issue by including it as a fundamental policy action for the environment and has published a specific Guide for decision-makers [31].

Agroforestry systems help promote resource efficiency and support an agricultural economy based on ES. Therefore, the agroforestry role in supplying numerous ES is crucial for integrating trees in herbaceous agricultural systems, implementing a potential sustainable land-use system that combines production with natural resources conservation in temperate regions [25].

This case study focuses on a territorial scale, to assess the provisioning of ES thanks to the presence of GI connection systems between roads, waterways, fields, agroforestry systems and city suburb.

#### 2.1.2 ES assessment tools

Several researchers have focused their work on developing tools, instruments - mainly models – and frameworks, useful to evaluate the impact of environmental regeneration projects and their return in terms of provided ES. Indeed, decision-makers and stakeholders need instruments capable of forecasting the impact and the consequences of their choices, and these models can represent a productive tool for them to have reliable predictions [32]. Therefore, as this research field is gaining attention, there is a higher demand for tools capable of evaluating and forecasting each requalification choice's impact, affecting policy decisions [33, 34, 35]. As in other scientific disciplines, these tools are specific models, capable of assessing and forecasting spatially explicit information outputs about ES provision. In the last years, different tools could assess ES. They are usually freely available: the major ones - such as InVEST (Integrated Valuation of Ecosystem Services and Trade-offs), ARIES (ARtificial Intelligence for Ecosystem Services), EVT (Ecosystem Valuation Toolkit), and I-Tree ECO - have been tested in different environments and were used to conduct multiple peer-reviewed papers [36], as it emerges from several studies [19, 20, 21, 37].

Therefore, only with reliable tools and instruments, it can be possible to conduct ES assessment and forecast, useful to support the decision-making process. This activity is now possible by choosing the most appropriate tool available, depending on the particular needs, data and requests.

#### 2.1.3. Objectives:

Starting with these assumptions, the goals of the present study are to:

i) assess and quantify the ES provided by two possible and alternative requalification scenarios;
ii) estimate the impact of these scenarios, analysing the ES provision in the next 30 years;
iii) explore the relationship of the ES's provision in the two alternatives, thanks to the treemap analysis, to understand and underline the pros and cons of each requalification choice.

### 2.2 Materials and Methods

#### 2.2.1 Case study

In the analysed case study, we quantify and assess ES's provision by a peri-urban requalification. This requalification focuses on implementing a GI consisting of a net of trees and shrubs within peri-urban agricultural fields, following an overall agroecological approach - primarily intended to connect rural areas with the urban ones providing several ES.

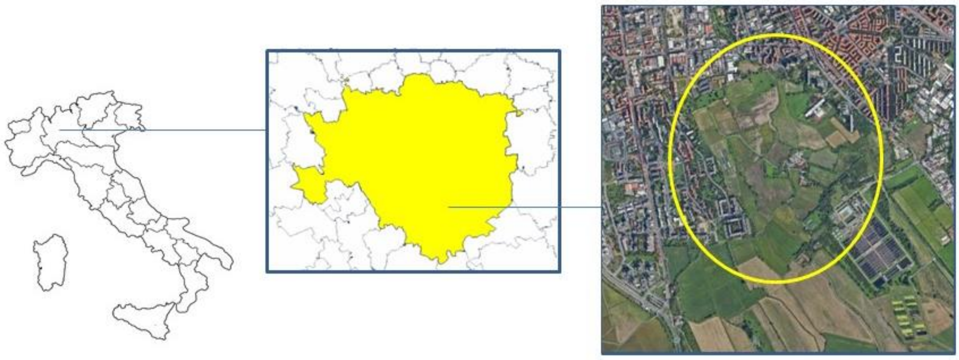

**Fig. 2** The area of the case study, situated in the peri-urban area of Milan, Italy.

The requalification project took place in the south part of Milan. This city has a 23% (4,231.74 ha) of its territory in South Milan Agricultural Regional Park, which is part of a plan of protection and enhancement for all the elements that characterise the agricultural landscape. This Agricultural Park forms a denser city contour, along the town's southern arch, providing more dynamic agricultural economy and less favourable infrastructural conditions. The continuity of the agrarian territory characterises the horizons of the low Lombardy plain.

Within the municipality of Milan, the landscape component expressed by the agricultural territory necessarily has a limited but not less significant extension, both in terms of the preservation of memory and the historical, or rather original, characters of the urban context, both under the role that is now sustainable by the peri-urban open spaces towards a demand for quality of the environment and expectations for a renewed relationship with agricultural production expressed by citizens.

In this context, the project - named Milano Porta Verde (MPV) - collects the legacy of the European project "OpenAgri", aiming to extend its lifespan till 2030. In 2017, the Municipality of Milan launched the "OpenAgri - New Skills for New Jobs in Peri-urban Agriculture" project. Together with 16 partners, the Municipality of Milan had been awarded in the "Urban Innovative Actions" call, funded by the European Regional Development Fund (ERDF), to fund innovative proposals that address urban issues, such as environmental and socio-economic problems. The project was finished in 2020 and focused on innovative ideas to face urban challenges relevant to the future by creating a new innovative agricultural centre, worth 6 million euros.

As OpenAgri, the MPV project wants to experiment with new territorial development models that conceive the city and the countryside as a single organism and stage the possible paths towards sustainability of human settlement and food production, improving local citizens' well-being impoverishing life in the soil. The interested peri-urban area could be an agroecological pioneer project open to the territory by creating a link between the human community and food production in a sustainable environment. The project lays the foundations for creating, through a participatory approach, an agroforestry park, which aims to be productive, experimental, demonstrative and didactic. The project stages a pilot experience of a new paradigm of agriculture, environment, landscape, and society, parallel with similar European Network experiences: the MPV has already been named as a notable case study within the European "Liaison" framework as an ambitious pilot project of European Rural Innovation Ambassadors [38].

This proposal adds to agriculture the typical advantages of complex forest systems becoming an urban regenerative agricultural centre, which aims to be one of Europe's first experiences of a peri-urban experimental approach to an agroforestry system. The primary production function of food sources takes place together with the generation of ES connected with biodiversity, carbon sequestration, environmental quality, work and social cohesion, at the same time involving the various territorial subjects in innovative strategies for accessing the food market at zero km, connected to educational and didactic-educational activities.

The MPV project aims at:

- Regenerating the project area, through the implementation of an agroforestry plan based on a network of living fences constituted of trees and shrubs;
- Incubating the know-how of a pool of innovative start-ups selected from the OpenAgri project, of associations operating in the area and of the Milanese universities;
- Laying the foundations for an open-source digital library of already tested sustainable agricultural practices;
- Testing a new model of economic and financial management of investments in agriculture, with the opening towards the Agricultural Support Communities (CSA);
- Becoming the ideal place to host the experimentation of the most innovative environmental, meteorological and ecological monitoring technologies, in an Open Source IoT context;
- Helping citizens achieve sustainable development goals, facing this millennium's challenges on Food Security and environmental regeneration, with a continuous training and educative approach.

Thanks to the area's ecological rehabilitation, the neighbourhoods' inhabitants will witness the restoration of a peri-urban agricultural area with strong agroecological potential.

#### 2.2.2. Data Collection and database construction

The MPV project covers 45 hectares of agricultural fields. Since the overall requalification is at the starting point, we built a database encompassing two different scenarios to run our ES analysis. The first one uses the available information, given by the project proposers, about the tree network's extension and characteristics. Therefore, this first scenario and the following analysis focus on the real project accepted in future planning.

The database for the scenarios includes a network of trees and shrubs, divided into two typologies.

The first scenario (figure 3) named "Milano Porta Verde Hedgerows" (MPV-H) includes vegetation planted as a single tree and shrubs line, situated on the area's hedges, dividing some fields and the project area from the surroundings. In the MPV-H scenario, trees and shrubs were mainly placed on the fields' hedges traditionally cultivated. The implant line of trees and shrubs considers standard distances: 1,2 m between plants.

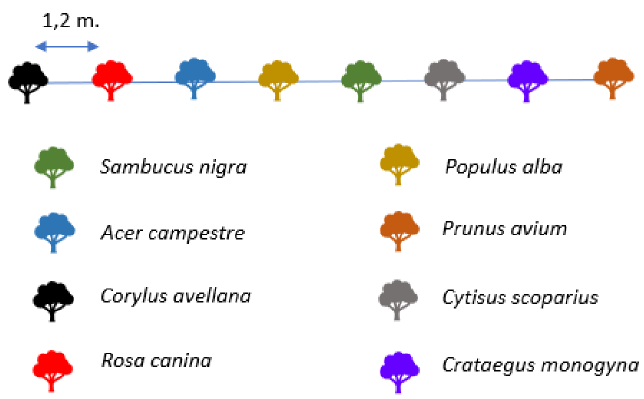


**Fig.3** The plantation scheme used in the first scenario (MPV-H), on the single line of trees and shrubs, the distance between elements is 1,2 m.

The second scenario (figure 4) named "Milano Porta Verde Agroforestry" (MPV-A) includes an alley-cropping system based on an own research proposal simulating the ES provided by implementing a stronger agroforestry plan, taking inspiration from the European literature [39]. In this agroforestry scenario, we propose to cover half of the area – 22,5 hectares – with trees and shrubs focusing on a standard plot of 100 m x 100 m. We propose a line of trees and shrubs every 10 meters, with a distance between the plants on the same line of 4 m, the total number per plot is 250 plants. Moreover, we propose to plant bigger trees – trunk diameter of 2 cm. for shrubs, 4 cm. for trees (tab. 1) - to have a higher ES level since the beginning of the project.

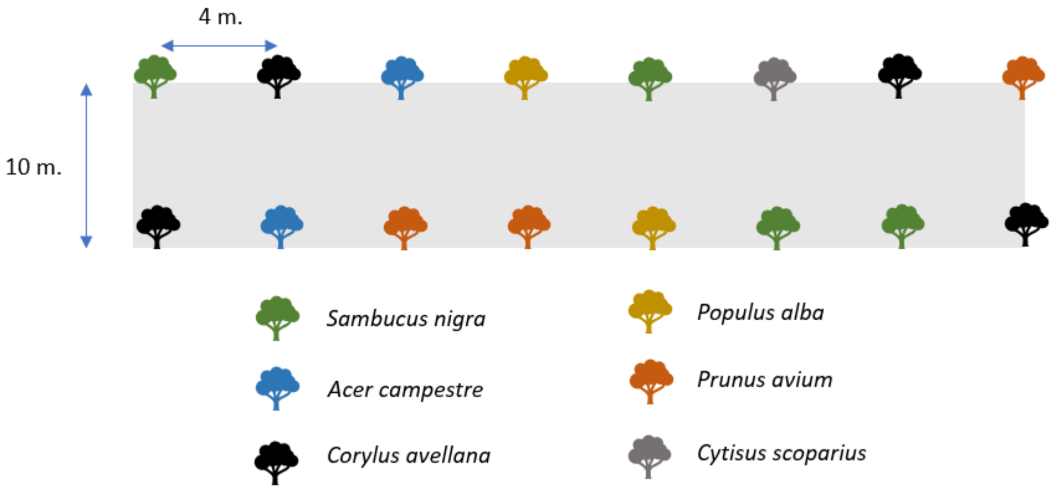


**Fig.4** The plantation scheme used in the second scenario (MPV-A). The distances between the lines of trees and shrubs are 10 m, and the distance between each element on the same line is 4 m.

Summing up the adopted decisions to run the simulation with I-Tree Eco model, the main elements of the two considered scenarios are:

1. The same typology of tree and shrubs species. The species are mainly autochthonous plants according to the regional policies. The number of plants and the scheme implant is different in the two scenarios.
2. Identification number (ID), represents the progressive number of the elements. This phase is essential for organising I-Tree Eco model dataset.
3. Land-use type has been by default set as agriculture land use from the Lombardy Region website. This information is essential for organising I-Tree Eco model dataset for the meteorological and soil information.
4. In the scenario, MPV-H the height and diameter at breast height (DBH) of each element, are deducted from the actual requalification plan, for the simulation of the second scenario we established measure considering an implant of more developed plants (table 1; figures 3 and 4).
5. The information about light exposure of each element was different, considering MPV-H and MPV-A (table 1).
6. The health parameter of plants has been set at the maximum level since all the plant materials come from certified nurseries.
7. The type of position of each element is crucial to simulate tree growth and development, and, due to the plantation scheme, it has been set as a non-street tree, with proper space to develop without interferences (figures 3 and 4).

Moreover, the two configurations follow a different approach. The first scenario – the one proposed and foreseen in the project papers - is planned to use small-density plants with a higher density of plantation, and trunk diameters vary from 0,5 cm to 2 cm. This choice is typical of agroforestry and is due to budget limitations too. Conversely, the second configuration uses already developed trees – trunk diameter of 4 cm -, while it has a minor density of elements. This solution represents an interesting alternative to deliver higher ES levels from the beginning of the project.

| | **Distance between plants** | **Overall Tree/shrub number** | **Shrub/Tree diameter** | **Land-use Type** | **Crown Light Exposure** | **Health parameter** | **Type of position** |
|---|---|---|---|---|---|---|---|
| **Scenario 1, MPV-H** | 1,2 m. | 9260 | 0,5-2 cm. | Agriculture | 4 | 100 % | No street |
| **Scenario 2, MPV-A** | 4 m. | 5625 | 2-4 cm. | Agriculture | 5 | 100 % | No street |

**Tab. 1** Differences between the two analysed scenarios and relative input are useful for running the ES assessment with the selected software.

That information is needed to calculate the ES provided by the tree network and simulate the thirty-year forecasting in the two scenarios.

#### 2.2.3. Selected Ecosystem Services

The MPV – and the previous OpenAgri project – provides a wide range of ES, since it deals with the requalification of an area with several issues, beyond environmental aspects, considering the social and the economic needs of the area. Anyhow, in this study, we decide to focus on the regulating ES provided by trees and shrubs. This choice is due to multiple considerations and analysis: first of all, the cultural ES – such as recreational activities, and other social aspects – need a more extended period to be provided and the project is still at a starting point of many initiatives – e.g., a Community Supported Agriculture (CSA) set up – so a broader analysis of socio-economic ES could be done after their establishment, estimated in at least five years. Moreover, other studies evaluated the LCA impact of the OpenAgri start-up as an impetus for urban regeneration [40].

This study investigates the environmental impact of the area's requalification, focusing on the regulating ES provided by trees and shrubs. Moreover, we analysed the ones linked to the Carbon cycle, air quality, and avoided run-off within the regulating ES set. This selection considers the environmental issues of the urban area where MPV is located. Indeed, Milan is suffering from continuative air pollution problems: the city and surroundings are above the critical level of concentration of each primary air pollutant ($O_3$, $NO_2$, PM 2,5 and PM 10), and it is also witnessing a growing percentage of soil sealing, with adverse effects on water management [41].

Therefore, in the light of this focus on the contribution of trees and shrubs to the requalification project and their role in providing ES, we considered I-Tree Eco as the ideal tool among the available software, using the database as input for the software.

This software was specifically developed to help researchers assessing urban and peri-urban forest value and its functions. Several models are included within the software to assess and evaluate the different ES provided by trees and shrubs. Indeed, I-Tree Eco is designed to use standardised data from previously prepared inventory (or available databases, as in this case study), hourly air pollution and meteorological data to quantify urban forest structure and numerous urban forest effects.

The software has been firstly used in the US, and it has been chosen because of its reliability, state-of-the-art technology, being peer-reviewed and recommended by the USDA Forest Service. I-Tree Eco can assess the structure of the analysed urban and peri-urban forest in terms of species composition, leaf area and biomass, and evaluate the associated regulating ES, such as carbon storage sequestration; air pollutants removed hourly and the avoided run-off. For each of these ES, I-Tree Eco can assign a monetary value, therefore giving an overall value to the database, helping determine its value [42].

The database covers all the minimum requirements needed by I-Tree Eco to simulate and assess the following ES:

- Air Pollution Removal.

Trees and shrubs improve air quality in several ways, such as decreasing air temperature, directly removing pollutants, and reducing energy consumption in buildings, thus providing significant regulating ES to the local environment. I-Tree Eco calculates the amount of ozone ($O_3$), sulphur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), carbon monoxide (CO) and particulates less than 2,5 microns (PM 2,5), removed by the vegetation year after year.

The removed quantities are estimated using the hourly tree-canopy resistances for ozone, while estimates related to sulphur and nitrogen dioxides are based on a hybrid of big-leaf and multi-layer canopy deposition models [43, 44]. Since the absorption of carbon monoxide and PM 2,5 by vegetation is not directly related to transpiration, removal rates (deposition velocities) are calculated using values from the literature [45], then calibrated using leaf phenology and leaf area. Moreover, PM 2,5 removal considers a resuspension rate (50 %) of particles back to the atmosphere [46]. Indeed, plants absorb PM 2,5 when it is deposited on leaf surfaces [47]. However, this deposited PM 2,5 can be returned into the atmosphere during rain events, dissolved or transferred to the soil. These phenomena can lead to positive or negative pollution removal quantities, depending on various atmospheric factors.

I-Tree Eco bases its analysis on user-defined local pollution. In the present case study, values refer to the nearest meteorological station, in Milano Linate, close to the MPV area.

- Carbon Storage and Sequestration.

As known, woody plants contribute to the mitigation of climate change by sequestering and stocking atmospheric carbon in tissue, thus decreasing the atmosphere's carbon dioxide levels [48].

Carbon storage defines the quantity of carbon accumulated in the above-ground and below-ground parts of woody vegetation. Equations from literature and available tree data show that compared to traditional forest trees, open-grown trees – as the urban and peri-urban ones – tend to have less biomass [49]. In order to consider that difference, biomass results were multiplied by 0,8. The calculation of the tree dry-weight biomass was the stored carbon by multiplying by 0,5.

Carbon sequestration is instead defined as the removal of carbon dioxide from the air by plants. To calculate the amount of carbon sequestered annually, I-Tree Eco considers average diameter growth from the proper genera, diameter class and tree condition. These data are added to the existing tree diameter, incrementing tree size step by step each year.

- Oxygen Production.

To quantity the oxygen produced by trees and shrubs in the project, the calculation considers carbon sequestration based on atomic weights: net $O_2$ release (kg/yr.) = net C sequestration (kg/yr.) × 32/12. The net carbon sequestration rate is the carbon sequestered due to the annual tree growth and reduced, considering the amount of carbon lost due to tree mortality and decomposition [50].

- Avoided Run-off.

When it rains, water can follow different paths: thanks to the vegetation, it is partly intercepted by trees and shrubs, avoiding the soil's achievement. The water falling to the ground could give away in the soil, either becoming surface run-off or spreading on the ground. In urban areas, the large percentage of impervious and paved surfaces increases the amount of surface run-off. Trees and shrubs can intercept water, thus resulting in decisive in reducing surface run-off. I-Tree Eco calculates the annual avoided surface run-off thanks to trees and shrubs' presence by estimating the quantity of rainfall intercepted by vegetation. In particular, the model is capable of calculating the difference between annual run-off with and without vegetation. I-Tree Eco considers only the amount of water intercepted by the above-ground biomass: this means that the overall avoided run-off might be more significant, since the other factors – e.g., soil cover – affect it.

### 2.2.4. Ecosystem services forecasting

Once evaluated the current ES provision level, in order to understand the tree network's growth and development in the next future and the related ES increase, a simulation was conducted to assess ES provisioning in the next thirty years.

The simulation started using an extension of I-Tree Eco – the i-Tree Forecast model –, developed by the USDA Forest Service to assess future changes in urban and peri-urban forest structure and function. The tool estimates future changes both in dimension (e.g., diameter) and in condition from the initially given structure. Indeed, it mainly takes into consideration three aspects of tree life: growth, establishment and mortality. Growth is estimated based on several parameters, such as growing season length, species-specific growth rates, tree condition and tree maturity. Tree mortality is estimated using a fixed input mortality rate, considering the optimal condition of the planted trees [51]: this rate can change, and the user can adjust it, and it depends on the starting health condition and the dieback of each tree. Even if it is possible to include in the extreme simulation events - such as bad weather or the presence of parasites - and their impacts on the vegetation and consequently on ES provision, we decided not to insert this possibility, in order to have a clear view of the potential ES provided in the area without any possible interference of external agents, to have an overall comparison between the two analysed scenarios.

### 2.2.5. Treemap

To better understand the results and the relationships between ES, we tested the treemap methodology. We use Excel file for immediate space-filling visualisation of the different items' hierarchy to apply the I-Tree Eco results for the treemap [52]. A treemap is usually composed of root rectangles groups that represent the items of the study. The treemap successfully helps to visualise big data [53]. On the other hand, the treemap represents only one future scenario as it represents one moment in time. The possibility of highlighting immediate outliers and the clear hierarchical grouping enabling single scenario evaluation has not been used yet to explore forecasting scenarios.

## 2.3. Results

### 2.3.1. Provided Ecosystem Services

I-Tree Eco's results regard the tree population's structure and composition for each studied scenario. Showing a quantification of the tree cover, leaf area and leaf biomass provided by the trees and shrubs in the area. In MPV-H scenario, the predominant species are *Sambucus nigra*, *Salix caprea* and *Rosa canina*, respectively with the 11%, 10,2% and 9,5% of total population (9260 elements). Trees cover about 3,308 hectares and provide 8,611 hectares of leaf area. However, the population percentage does not correspond to an equal percentage of leaf area, as it emerged from the results due to each species' particular biological and morphological characteristics.

| Species name | Percentage of Population (%) | Percentage of Leaf Area (%) |
|---|---|---|
| *Sambucus nigra* | 11,0 | 18,4 |
| *Rosa canina* | 9,5 | 9,0 |
| *Acer campestre* | 7,4 | 10,4 |
| *Prunus spinosa* | 8,2 | 8,4 |
| *Salix caprea* | 10,2 | 5,2 |
| *Crataegus monogyna* | 6,7 | 5,5 |
| *Cytisus scoparius* | 4,9 | 6,0 |
| *Viburnum opulus* | 3,4 | 7,4 |
| *Quercus robur* | 4,4 | 3,8 |

| | | |
|---|---|---|
| *Corylus avellana* | 3,3 | 4,4 |

**Tab. 2** The principal species present in the first scenario, with a percentage of the population and correspondent leaf area.

On the other hand, the second scenario assumed to use more plant elements, occupying a greater soil area, and, at the same time, less density of plants on the rows. This scenario's implementation – 5625 plants – would assure a similar tree cover (3,29 ha) and leaf area (9,81 ha).

| **Species name** | **Percentage of Population (%)** | **Percentage of Leaf Area (%)** |
|---|---|---|
| *Sambucus nigra* | 16,0 | 19,2 |
| *Acer campestre* | 12,0 | 14,9 |
| *Cytisus scoparius* | 12,0 | 13,7 |
| *Corylus avellana* | 12,0 | 13,4 |
| *Prunus spinosa* | 8,0 | 7,7 |
| *Populus alba* | 8,0 | 3,1 |
| *Quercus robur* | 4,0 | 3,2 |
| *Fraxinus angustifolia* | 4,0 | 3,0 |

**Tab. 3** The principal species present in the second scenario, with percentage population and correspondent leaf area.

- Air Pollution Removal:

Regarding the air pollution removal, the removed pollutants' level depends on tree size and the abundance of the pollutant in the air. For example, if trees are close to a street, thus with a high presence of particulate, the trees will tend to absorb more while growing; while if they are in a less polluted area – e.g., countryside or a park - the level of pollutant at microscale will be minor; therefore, the overall assumption will not increase as much. In our case study, the peri-urban forest is in an agricultural area, with a low air pollutants presence at micro-scale. Indeed, I-Tree Eco uses "Agriculture" as a land-use type.

Pollution removal by trees was estimated using the database and the recent available pollution and weather data available from Milan Linate Airport weather station. Ozone was the most removed pollutant. In the first scenario, the agroecological net of trees and shrubs removes a total of 123 kilograms of air pollutants per year, encompassing ozone ($O_3$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), PM2,5, and sulphur dioxide ($SO_2$). Moreover, the vegetation emits an estimated 47,15 kilograms of volatile organic compounds (VOCs) - 41,81 kilograms of isoprene and 5,341 kilograms of monoterpenes. The species that tend to emit higher VOCs levels are *Salix caprea* and *Quercus robur*: emissions vary among species due to species characteristics and leaf biomass.

In the other scenario, the agroforestry network can remove 128,5 kg per year of overall pollutants, while producing 62,58 kg per year of VOCs.

- Carbon Storage and Sequestration:

Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered can increase as far as the tree's dimension and health increase. In the first case, I-Tree estimates the gross sequestration equal to 1,212 metric tons of carbon per year; while in the second one, the estimation is equal to 5,59 tons per year.

Regarding carbon storage, the first scenario stored 1,16 metric tons of carbon. Of the species sampled, *Acer campestre* stores the most carbon (approximately 10,6% of the total carbon stored), and *Sambucus nigra* sequesters the most (approximately 10,5% of all sequestered carbon). The second one can store 7,8 ton. of carbon, mainly thanks to a more significant dimension of the trees and related bigger trunk diameter.

- Oxygen Production.

Oxygen production is one of the most known benefits of trees. The tree's annual oxygen production is directly related to the amount of carbon sequestered by the tree, tied to tree biomass accumulation. In our study, the first scenario is estimated to produce 3,233 tons of oxygen per year, while the alternative produces 14,91 tons per year.

- Avoided Run-off:

Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. Avoided run-off is estimated based on local weather from the user-designated weather station – Milan Linate for both the scenario. In the first case, the trees and shrubs help to reduce the run-off by an estimated 265 cubic meter per year; meanwhile, the contribution is 286,9 cubic meter per year in the second scenario.

| | **Tree cover** | **Leaf area** | **C storage** | **C sequestration** | **Air pollution removal** | **Avoided Run-off** | **Oxygen production** |
|---|---|---|---|---|---|---|---|
| **Scenario 1, MPV-H** | 3,308 ha | 8,611 ha | 1,165 t | 1,212 t/yr. | 123 kg/yr. | 264,6 $m^3$/yr. | 3,233 t/yr. |
| **Scenario 2, MPV-A** | 3,296 ha | 9,81 ha | 7,8 t | 5,59 t/yr. | 128 kg/yr. | 286,9 $m^3$/yr. | 14,91 t/yr. |

**Tab. 4** Comparison between the ES provided at year 0 by the two different alternative scenarios.

### 2.3.2. Ecosystem Services Forecast

After quantifying the provided ES at the planting time, we focused on understanding how the peri-urban forest could contribute in terms of ES in the next thirty years, and which configuration could guarantee a higher ES level in the future.

Using the I-Tree Eco model's forecasting extension with the described parameters, we simulated several parameters and ES. Some of these (e.g., tree cover, leaf area, leaf biomass) refer to the vegetation growth and development; other are linked to ES provision (C storage and sequestration, removal of $O_3$, $NO_2$ and $SO_2$).

In general, as trees and shrubs grow, the environmental benefits increase too, resulting in an improvement of ES levels. Anyhow, in our case study, it is interesting to quantify the differences between the two scenarios in the next thirty years.

| | **Tree cover** | **Leaf area** | **C storage** | **C sequestration** | **$NO_2$ removal** | **$SO_2$ removal** | **$O_3$ removal** |
|---|---|---|---|---|---|---|---|
| **Scenario 1** | 4,6 ha | 11,31 ha | 72,69 t | 4,48 t/yr. | 38,9 kg/yr. | 7,8 kg/yr. | 109,5 kg/yr. |
| **Scenario 2** | 9,76 ha | 62,67 ha | 478,5 t | 29,86 t/yr. | 95,4 kg/yr. | 18,8 kg/yr. | 266,4 kg/yr. |

**Tab. 5** Comparison between the ES provided at year 30 by the two different alternative scenarios.

### 2.3.3. Treemap

We visualised the results related to $O_3$, $NO_2$, $SO_2$, leaf area, leaf biomass, tree cover and C sequestration presenting the comparison between year 0 and 30 by the treemap (Figure 5) each of the analysed solution. The comparison of the two times showed clear results related to outliers and temporal trend of growth. Outliers are represented as $O_3$ in Year 30 and Year 0; and C sequestration for year 30 and Year 0. On the other hand, the treemap allows us to see how the indicators remain stable, excluding one: C sequestration, which has a considerable increase at Year 30.

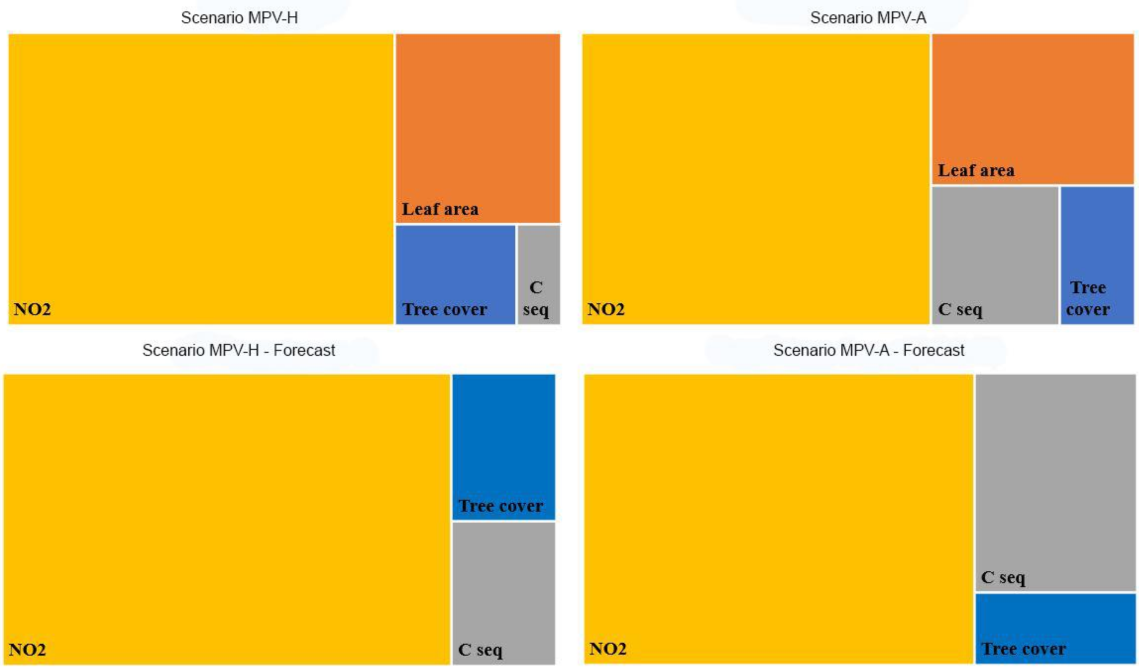


**Fig. 5** Treemap compares year 0 (above boxes) and 30 (below boxes) of the selected indicators.

### 2.4. Discussion

The selected software to run the simulation "I-Tree Eco" tested many types of researches in the last years, and thus it represents a reliable tool to assess the ES provided by trees and shrubs. However, it requires several inputs to run and give adequate feedback on the urban and peri-urban structures and functions: the optimal solution - recommended in the model guidelines - is to conduct a complete or plot inventory, to collect each needed parameter. In our case study, we had to follow a different approach: as the project is at a starting point, trees and shrubs are still planted. This situation prevented us from collecting data and forced us to extract the needed inputs from the available project documentation – a first scenario – and create a new database for the second one leading us to select the ES analysed in our work. To precisely assess the agroecological network's overall impact, we should need much more input (e.g., volume and dimension of each crown), clearly impossible to obtain from a project still ongoing.

The comparison of the two scenarios underlines an interesting difference in the ES provision and the vegetation structure. Each scenario shows our pros and cons that must carefully be evaluated as a requalification choice. Indeed, the project papers' data, referable to the first scenario, showed some limitations. Since the project considers the planting of several hectares, it requires significant economic efforts in materials (plants), both in workforce and labour, to prepare the soil to plant trees and shrubs. It is comprehensible that a project at a starting level may find some difficulties in facing these issues - large land extension in need of requalification and high costs - and therefore choose to plant trees and shrubs in small pots. On the one hand, it reduces costs but on the other hand, causes an initially reduced provision of ES, even if this initial minor provision of ES will ameliorate in the years thanks to trees' annual growth.

In the second scenario MPV-A, we wanted to understand which ES provision differences may occur using more developed trees, assuming no budget constraint but balancing the cost with a lower planting density due to a more significant tree dimension (see tab. 1).

Consideration about tree size regards, in particular, the ES related to carbon - storage and sequestration. Indeed, the rate of carbon accumulation grows year by year [41], because of the increasing total leaf area, which balances a lower productivity per unit of leaf area. This relatively new scientific assumption - even in the recent past, many researchers [54] theorised that after initial growth, the mass growth rate of individual trees declines with increasing tree size, with adverse effects on C storage and sequestration - is confirmed in our results, with a continuous improvement, year by year, of the activity of the tree.

Results show the ES provision thanks to implementing a simple network of trees and shrubs (MPV-H scenario).

An essential key in the ES provision is species-selection. The most successful species related to C sequestration, C storage and avoided run-off within our database is *Sambucus nigra*. Our results confirmed several studies that showed the potential role of *Sambucus nigra* in accumulating pollution, from the soil and the air. In particular, [55] showed the added value of this species in a peri-urban environment as it accumulated Fe, Cr, and Zn from the traffic pollution and made these elements available for human consumption as edible flowers. On the other hand, this species suffers from different types of air pollution. [56] Showed the effectiveness of *Sambucus nigra* for biomonitoring air pollutants as ozone as it is susceptible to it. Indeed, $O_3$ can be a challenge for plant survival, but particular species could absorb it in the long term [57]. A multi-trait approach and the i-Tree Eco model presented by [57] showed the effectiveness to absorb $O_3$ of other tree species, such as *Liriodendron tulipifera*, *Acer campestre*, *Acer platanoides* and *Celtis australis*, which are typical of the urban environment – parks and gardens – for their ornamental value too, and not suitable for agroforestry use. This study confirmed our results showing the highest difference of $O_3$ absorption and $NO_2$ absorption in 30 years. The potential of combining different species of trees – as in a peri-urban agroforestry system – appeared to be the key not only for regulating air pollution but also other regulating services [58, 59].

It is also noticeable that, at year 0, the higher density of the first scenario balances the smaller dimension of the plants, especially in terms of network structure: tree cover and leaf area have similar values, as the air pollution removal (123 kg/yr. vs 128 kg/yr.), thanks to the thicker barrier formed by the first scenario.

Overall, the results show the potential impact of the two proposed alternatives. Each one has its advantages, even if it emerges that, in quantitative terms, the second scenario provides higher regulating ES due to bigger plants choice at the implant. However, the first scenario may assure a longer vegetative cycle, and – of course – it represents an affordable solution that links ES provision and economic sustainability.

Another difference regards soil use: the first scenario aims at inserting an initial agroforestry approach, thanks to tree and shrub line between fields, in an area where monoculture is still predominant. The alternative one aims at implementing a stronger agroforestry plan, with trees and shrubs, not only on the hedges of the area and between fields, but inside these fields, occupying half of the overall area. Therefore, this second alternative commits the farmers to adopt a completer agroforestry management of their lands.

The results visualisation obtained with the treemap analysis (Figure 5) allowed us to deeply explore the relationship of the provision of the ES studied in the two alternatives. Furthermore, we can highlight the pros and cons of each requalification choice. The first scenario and the scenario agroforestry represented similar patterns, except for C sequestration. The agroforestry scenario presents higher C sequestration in the present condition and the forecasted scenario in 30 years. This result is coherent with the body of literature that envisioned agroforestry solutions as a sustainable environmental practice for carbon sequestration [60].

Nevertheless, both scenarios will increase biodiversity – by using at the same time several trees and shrubs species – which can lead to multiple benefits and ES, rather than a classic use of few species, or worst, the total absence of trees and shrubs in agricultural fields, which is typical of modern agriculture with a pure monoculture approach, in Milan area too.

Moreover, the MPV project deals with the requalification of a neglected peri-urban area. Beyond environmental aspects, the project has a social and cultural relevance too. This relevance can be proved and measured by looking at various aspects, as new job opportunities in the area due to the establishment of new farms and cultural ES provided by the requalification project. These ES – purely immaterial – can also be provided by the network of trees and shrubs, increasing the project's overall importance.

Therefore, although considering a selection of ES, the research shows an effective and replicable strategy to provide ES in urban and peri-urban environments.

The analysis conducted represents a starting point in assessing and evaluating requalification projects' contribution to ecosystem services. This approach could be useful in different areas and cases of study, as well as it could be expanded with the concomitant use of multiple techniques (e.g., software and models) to assess a superior number of ES.

### 2.5. Conclusions

The study shows that in urban and peri-urban regeneration projects, which are often taking place at the fringe-zone of our cities, it is possible to increase the provision of ES - and in particular of the regulating ones - thanks to the implementation of GI connected with agroecological projects for implementing networks of trees and shrubs.

This case study in Milan, with the MPV project, aims at requalifying a neglected part of the city, mainly thanks to urban and peri-urban agriculture exploiting the provision of ES thanks to the GI development like a network of trees and shrubs. The research analyses two alternative solutions, with different plantation schemes, tree sizes and densities. Results show that the presence and the future development of this network, in both the configurations, assure several ES, such as carbon sequestration, carbon storage, and an overall air quality improvement. The choice between the two alternatives depends on several aspects, as agricultural management, available time for the requalification and economic resources. The evaluation of trees and shrubs' role has been carried out thanks to the specific software - I-Tree Eco - to better understand and analyse ecological, economic and social benefits derived by their presence. The Milano Porta Verde's case study represents challenges and opportunities linked to each requalification project, being a replicable example in similar conditions. Indeed, thanks to a careful species-selection, it is possible to assure an increasing amount of regulating ES, providing a cost-effective solution and the ongoing requalification project.

**Author Contributions:** Conceptualization, Ambrogio Zanzi, Federico Andreotti; methodology, Ambrogio Zanzi, Federico Andreotti; software, Ambrogio Zanzi, Federico Andreotti; validation, Stefano Bocchi; investigation, Ambrogio Zanzi, Federico Andreotti, Valentina Vaglia; data curation, Valentina Vaglia; writing—original draft preparation, Ambrogio Zanzi, Federico Andreotti, Valentina Vaglia; writing—review and editing, Sumer Alali, Francesca Orlando; supervision, Stefano Bocchi. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgements:** The authors are thankful to Milano Porta Verde project partners for the information and the data provided to conduct the present study.

**Conflicts of Interest:** The authors declare no conflict of interest.

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## 3. ES provision and socio-economic issues

**Chapter introduction**

The following chapter is focused on the relationship between ES and socio-economic issues in developed countries. Indeed, well before Covid-19 pandemic, many sectors of our society were already suffering, especially in terms of job opportunities and fair access to decent economic levels. These difficulties are amplified in particular social and territorial niches: in the last years, economic and social crisis has hit hard in particular youngsters, with a marked increase in unemployed people, and peri-urban areas, where the lack of resources and the failure of territorial planning have caused a growing urban sprawl, leaving territorial scars within our cities.

To assess the positive relation between ES provision and job opportunities we took as case study the European project OpenAgri, whose aims are the trainings of unoccupied people in the field of agriculture, with the motto "*new skills for new jobs"*, and the requalification of an historically dismissed area – 35 hectares – at the southern gates of Milan. The area, in the last decades, has witnessed a series of territorial planning mistakes, the abandon of the last cultivated fields and a consequent building activity without any coordination or plans, resulting in an environmental disaster due to illegal activities. The area and its recent pasts are also the living proof of the close link between the social malaise and degraded environmental conditions. Therefore, we conducted a scientific analysis to the European project and its activities, to assess and quantify which ES are provided, and how they foster job opportunities. These research activities have been conducted thanks to application of specific models and tailored indicators to first quantify ES levels, and then, to assess their link with the socio-economic dimension, thanks to Pareto Frontiers algorithm and Principal Component Analysis, to highlight trade-offs and to show the simultaneous enhancement of ES and incomes.

The paper has been accepted as book chapter of Springers book "*New form of Urban Agriculture*" whose publication is expected in 2021.

# Assessing ecosystem services and job opportunities in peri-urban agriculture start-up projects

Ambrogio Zanzi[1], Federico Andreotti[2], Valentina Vaglia[1], Sumer Alali[1], Francesca Orlando[3], and Stefano Bocchi[1]

**Abstract**

Significant socio-economic changes have occurred in the last decades: among all, increased migration from rural to urban areas. It appears clear that there is a need for resilient cities, capable of combining economic and environmental sustainability. Agroecological practices, as a reduction in agrochemicals input and extended use of living fences and tree rows, can improve environmental quality, assuring ecosystem services and urban food systems, and foster local productions and socio-economic tissue, improving the overall quality of life. That is the approach of the "Urban Innovative Action" OpenAgri project, aimed at the restoration of a 35-hectare peri-urban area in Milan (Italy), thanks to the creation of a start-up incubator focused on food production and at the agroecological transformation of the area. This work focuses on the quantification and the evaluation of strategies for enhancing ecosystem services and investigating their link with job opportunities. Thanks to the Pareto Front algorithm and Principal Component Analysis, we were able to understand which start-up approach could both provide new job positions and better ecosystem services. In the research, OpenAgri emerges clearly as one of the first case studies which combine urban requalification with socio-economic issues, representing a scalable strategy in other areas, to solve the increasing need for sustainability. Our results highlight that a multidisciplinary approach is needed, both to stay on the market and to supply ecosystem services, combining productive, social and environmental initiatives, resulting in the more suitable solutions to enhance the value of urban and peri-urban ecosystems, while addressing the actual socio-economic themes and creating new jobs.

**Key Words:** Ecosystem services; Agroecology; Job opportunities; Sustainable peri-urban development.

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### 3.1 Ecosystem Services

In recent years, the concept of Ecosystem Services (ES) has gained primary attention in scientific communities, and, after the publication of the Millennium Ecosystem Assessment (MEA, 2005), an increasing body of research is focusing on the quantification of ES in various environments (Bagstad et al. 2013; Costanza et al. 1997; Malinga et al. 2015).

We adopt the MEA definition of ES that, "Ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating, and cultural services that directly affect people and the supporting services needed to maintain other services" (MEA, 2005). This classification, updated recently, recognises at least 22 types of ES, divided into four categories: supporting, provisioning, regulating and cultural services (Fig X.1) (Daily, 1997; MEA, 2005; TEEB, 2010).

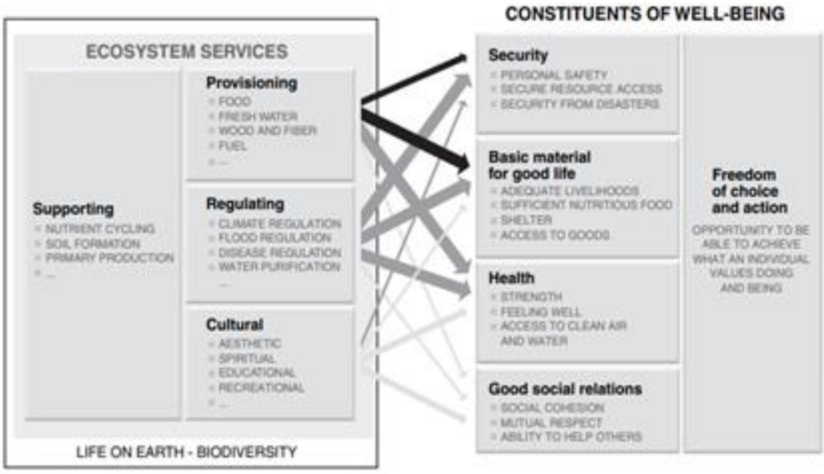


**Fig. X.1** Ecosystem Services classification and link with Human Well-Being. The figure highlights the MEA classification of ES and several links with human life. Source: Millennium Ecosystem Assessment, 2005.

The classification of ES into unique categories is useful to understand how deep and vast are the benefits we receive every day from our natural environment. Indeed, different habitats and environments can provide multiple ES at the same time. For example, forests are crucial for carbon storage and sequestration, while agroecosystems, definable as a system characterised by both ecological and agricultural processes, are crucial for food production and supply. Therefore, it is clear that urban ecosystems are essential to improve the liveability of our cities, assuring services with a direct impact on human health and well-being: e.g., air purification, climate regulation and noise reduction, as well as indirect and less tangible services, such as recreational and cultural activities dependent on the presence of nature in our urban agglomerate. Many researchers have now focused their attention on urban ES. The reason is logical apparent: since 2008, more than half of the world's population lives in cities. Moreover, by 2050, the percentage will grow up to 70 % - compared to only 13% in 1900 (Salbitano et al., 2016) - due to increased migration from rural to urban areas, which is one of the significant socio-economic changes and the main challenge of our time (Kovats et al., 2014).

In order to reduce the disservices of the urban area (i.e. waterproofing, air quality problems) which affect both socio-economic conditions and natural capital, there is an urgent need for new strategies to improve the ES provided by our urban environments to reach the sustainable urban development goals as defined in Agenda 2030 (UN, 2015). However, if compared to natural ecosystems, it is only recently that the scientific community has turned attention to the urban condition. Thus, the research in urban ES quantification is still in an initial phase (Gomez-Baggethun, Barton, 2012).

Starting from these assumptions, in this chapter, we analyse the link between the provision of ES and job opportunities in the urban and peri-urban context. Until today, few researchers have investigated this relation, which, in our opinion, is crucial in our cities, where the need for new jobs grows as fast as the demand for local food supply. This study focuses on the EU-funded project "OpenAgri" in Milan, in order to:

i) explore the trade-offs and synergies among the different start-ups of the project;

ii) estimate the potential contribution to the provision of ES by the start-ups under the OpenAgri within the Urban Innovative Action program; and

iii) quantify the ES provided by the ecological requalification of the project area.

### 3.2 Urban Agriculture and Ecosystem Services

Human-dominated ecosystems, as cities are, consists of urban ecosystems that include naturalised spaces – parks, urban forest, yards and gardens, wetlands, rivers, lakes, and ponds – that are directly managed or affected by the urban core and suburban lands, including peri-urban forests and cultivated fields (Pickett et al., 2001). In the urban context, naturalised ecosystems are highly modified and fragmented, and the components, such as individual trees, water and soil surfaces, are simultaneously involved in the delivery of ecosystem services (Nowak and Crane, 2002).

In public opinion, urban ecosystems that provide human health and well-being in cities, are the so-called: 'green infrastructure' (EEA, 2011; DG Environment, 2012). This term suggests the primary role, in an anthropic environment, that water and vegetation play in delivering ES at different spatial scales. However, crucial areas of the urban ecosystem are the urban agriculture (UA) areas which are often left out in analyses since it is non-typical of urban green infrastructure (Marthe et al., 2015).

Uncontrolled urban sprawl leads to increasing slum populations, inequalities, underemployment, sprawl and high demand for services and infrastructures (UN Habitat, 2014), as well as issues of food security and safety; cities are very dependent on surrounding ecosystems (Mörtberg et al. 2013; Bolund and Hunhammar, 1999). To balance these effects, urban and peri-urban agriculture allows providing ecosystem services, increasing the resilience of cities and enhancing human well-being (Alberti and Marzluff 2004). Urban and peri-urban agriculture provides cities with their local market of goods and services (Antrop 2000), having an impact on the mitigation of climate change, biodiversity loss, and land system change (Larondelle and Haase 2013).

This study explores the provision of ecosystem services provided by a case study of peri-urban agriculture in Milan, connecting with those studies that aim to assess the success of attempts to reduce the growing urban ecological footprint (Rees and Wackernagel, 1996)

### 3.3 Urban agriculture: new opportunities

Urban agriculture plays a potential primary role in providing food supply to expanding cities while connecting urban populations to the rural landscape. UA considers area within the cities; instead, peri-urban agriculture is a form of agriculture at the fringes of growing cities, characterised by the transition zone between urban and rural areas (Piorr et al. 2011). Peri-urban agriculture refers to as 'metropolitan agriculture' (Kittinger et al. 2016) or 'urban fringe agriculture' (Adams et al. 2013). Data on the increasing role of UA are available all over the world (Orsini et al. 2013). Indeed, today, as estimated by the Food and Agriculture Organization (FAO) in the initiative "Food for Cities", UA is practised by 800 million people worldwide (FAO, 2010), helping low-income urban residents save money on food purchases, often in still informal and disorganised ways.

In developing countries, UA is a strategy to address urban poverty improving health conditions and providing a more sustainable and stable economic growth at both family and community levels. In this context, the production derived by UA is complementary to the traditional agricultural production, since poor citizens can obtain perishable products such as vegetables, milk and eggs (van Veenhuizen 2006). In the poorest context, urban farming is an activity mainly practised for subsistence reasons, improving food systems for city supply. In fact, with the rise of food demand in cities, small-scale farming is conducted for the commercial purpose creating new job opportunities for the enterprises related to food production, processing and distribution (Cour 2001; Dossa et al. 2011, Agbonlahor et al. 2007).

Smart and resilient city governance increasingly promotes a better range of activities for redesigning degraded peri-urban areas—a location where ecosystem restoration can provide more benefits than costs (De Groot et al. 2013).  UA demonstrates the emerging ability of local start-ups and enterprises to develop new job skills that more efficiently connect the countryside with the city and better preserving diminishing patches of biodiversity (Kowarik, 2011). Start-up incubators and labs can shape not only the economy of urban and peri-urban areas but can also provide several ecosystem services related to their activities, including providing local food supply (Gerster-Bentaya, 2013).

### 3.4 Peri-urban agriculture case study

The European Union, within the "Urban Innovative Action" program, has funded the "OpenAgri" project in the Milan urban area. The main scope of the project is to create an open innovation centre dedicated to the theme of peri-urban agriculture and the agri-food chain. Milan is known as the "financial capital" of Italy, rich in cultural and social activities, and leading many economic sectors in Italy. Anyhow, despite this economic energy, there are clear signs of inequity. For example, the youth unemployment rate is high (28.6 %), but still, ten percentage points below the national average; and the percentage of NEETs, defined as young population (aged 15-29) not Engaged in Education, Employment or Training, in the metropolitan area is at 17.6 %, which is 2.0 % below the national figure (UIA, 2020).

The OpenAgri project study area considers the strategic peri-urban landscape, between the urbanised part of the city and the Parco Agricolo Sud, an agricultural and forested area connecting 61 municipalities, for a total 47,000 hectares (Fig. X.2). The improvement of the OpenAgri area will create an open innovation hub focused on peri-urban agriculture, including an ancient farm named Cascina Nosedo. Therefore, our case study deals with the agroecological requalification of an urban fringe area to serve as a living lab for social inclusion, jobs, and skills creation along the food supply chain while increasing the level of resilience and sustainability of the city (UIA, 2020). In this context, agroecology is considered an approach and discipline that seeks to integrate science (e.g., agronomy, sociology, history), practices and participation of the society (e.g., local knowledge, active indigenous participation) to guide research, policy, and action towards the sustainable transformation of the current agri-food system (Wezel et al. 2009, Gliessman et al. 2015, Méndez et al. 2016).

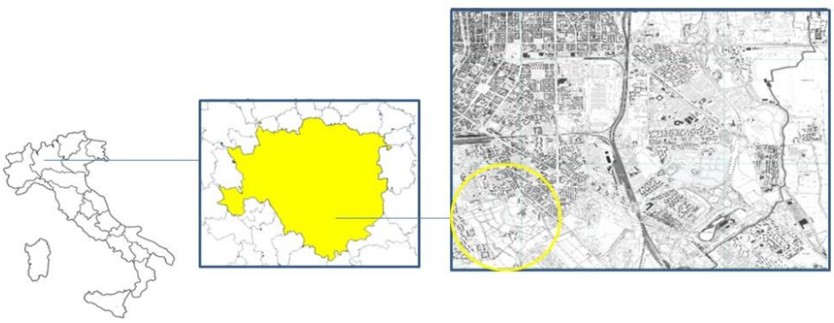

**Fig. X.2** Project area. OpenAgri is taking place in a 35 hectares area, in the south part of Milan metropolitan area, which is in the central part of the Lombardy region.

The OpenAgri project attracts resources to address the challenges formulated in the Food Policy promoted by the City of Milan, following the goals of the Milan Urban Food Policy Pact (MUFPP). In 2015 the Municipality of Milan adopted the MUFPP to develop a sustainable food system to assure healthy and accessible food, while reducing food waste in order to make urban food systems more inclusive, resilient, safe and diverse. Therefore, OpenAgri aimed to connect four different aspects: i) sustainability, by fostering a local food production and providing new ecosystem services in the project area; ii) system innovation, by the creation of a start-up incubator and to the requalification of a lost peri-urban area; iii) creation of new job opportunities; and iv) multidisciplinary approach since it reconciles food production, peri-urban requalification, and economic upturn. This economic upturn is needed both in the agricultural sector and in the Milan suburban social context. Indeed, even if the sector only represents 2% of Italy's Gross Domestic Product (GDP), it directly occupies more than 20% of the workforce and contributes substantially to Italian exports (ISTAT, 2017).

However, Italian agriculture has witnessed a contraction, both in production and in the workforce, by losing more than 100,000 people employed in the period 2013-2015 (ISTAT, 2018). That situation is in the European trend, where in the last ten years the agricultural workforce has marked a substantial decrease – with the loss of the 17.5 % jobs (ISMEA, 2018). The OpenAgri project in Milan can serve as an example of acceptable replicable practices to combine urban requalification, ecosystem services provided, together with the development of job opportunities and positive financial returns. This study opens a new field of research to better understand the relationship between economic performance and environmental aspects. The OpenAgri case study area consists of a network of agricultural fields, farms and historical buildings, including the Medieval Chiaravalle Abbey, linked together by the Vettabbia river. Thus, the area, with its long history, has witnessed many transformations, especially in the last century, influenced by urban sprawl and in a general abandonment and degradation (UIA OpenAgri report, 2018). This scenario led to the quality decay for both the environment and life-style for the resident population, also causing the crisis of contraction of local farms and agricultural production. For these reasons, it is urgent the requalification of the area to pave the way for the revitalisation of peri-urban agriculture.

### 3.5 OpenAgri ecosystem services and job opportunities

We analysed the performance of the start-ups selected by Milan municipality during the selection of the OpenAgri projects (Table X.1). In this section, we use a practical example to explain how we evaluated ecosystem services and job opportunities carried out by start-ups.

**Table X.1** List of start-ups working in the OpenAgri area and description of activities.

| **Start-up** | **Activities and target market** |
|---|---|
| Start-up 1 | Spirulina algae production |
| Start-up 2 | Agri-technologies for crops and vegetable production |
| Start-up 3 | Wildflower production and retail |

| | |
|---|---|
| Start-up 4 | Wheat cultivation for local bakers |
| Start-up 5 | Snail production |
| Start-up 6 | Seed production for local organic farmers |
| Start-up 7 | Wildflowers and edible plants production |
| Start-up 8 | Old cereal, hemp and *Paulownia* sp. Cultivation for the local market |

The evaluation of start-ups allowed us to address the following questions: (1) what are the ecosystem services (ES) and economic opportunities offered by start-ups in peri-urban areas? (2) Which start-up strategies can enhance the provision of multiple ecosystem services as well as economic incomes? In this chapter, we describe eight start-ups that were analysed to understand their potential contribution to ES provision and the relationship between ES and job opportunities.

We followed the Millennium Ecosystem Assessment (MEA) scheme (Figure X.1), considering the four ES categories. In our study, we have chosen to select and analyse several ES: in particular, six ES in order to investigate the link between their provision and job opportunities, and three ES supplied by the requalification of the area, thanks to the implant of new trees and shrubs (Table X.2).

**Table X.2** Indicators and measurements of different ES types by category

| **ES Category** | **ES Type** | **Indicators/Methods for measurement/Sources** |
|---|---|---|
| Provisioning | Primary Production | The monetary value of the products |

| | | |
|---|---|---|
| Provisioning | Secondary Production | The monetary value of the training sessions, cultural activities |
| Regulating | Pollination dependency | Klein et al. 2007, Aizen et al. 2009 |
| Regulating | Water use saved (WUS) | Ostrom et al. 1999, Hess et al. 2007 |
| Regulating | Air pollution removal* | i-Tree software (Nowak and Crane, 2000) |
| Regulating | Carbon Storage and Sequestration* | i-Tree software (Nowak and Crane, 2000) |
| Regulating | Oxygen Production* | i-Tree software (Nowak and Crane, 2000) |
| Cultural | Job opportunities | Data obtained from the start-up's business plan |
| Cultural | Start-up cooperation | Data obtained from the start-up's business plan evaluating the sharing of working force and/or materials, using the same selling systems |

We evaluated one provisioning ES, primary production, measured as the planned monetary value produced by each start-up after three years of activity. The data were collected based on the business plans presented by each start-up during the selection process. We also evaluate one provisioning ES, secondary production, obtained from minor incomes of each start-up, i.e., cultural activities and training courses.

We started evaluating the link between regulating ES and job opportunities, by focusing on two out the five regulatory ES under overall analysis: crop pollination dependency and water use saved. Crop pollination dependency is an essential ES to agriculture as almost 65 per cent of plant species need pollination by fauna (Klein et al. 2007). Concerning the essential animal-pollinated crops, over 40 per cent depends on wild pollinators, highlighting how crop production depends mainly on pollinators. Pollinator dependency is an ES proxy already well used for financial terms (ISTAT, 2018; Losey et al. 2006; Gallai et al. 2009) and production level (ISTAT, 2017; Aizen et al. 2009). We combined long-term data on global crop production and cultivated area provided by the FAO of the United Nations (FAOSTAT, 2007) for assessing the pollinator dependence on crop types. As defined by multiple authors (Klein et al. 2007, Aizen et al. 2009), we defined five classes of pollinator dependence: (a) none (production does not increase with animal pollination; class 0), (b) little (0–10 % production reduction; class 1), (c) modest (10–40 % reduction; class 2), (d) high (40–90 % reduction; class 3) and (e) essential (90 % reduction without pollinators; class 4).

For water used saved, we considered water as a common resource shared by a group of people with constraints associated with its management. Common-pool resources, as indicated by E. Ostrom, refers to natural resources where one person's usage can subtract from another usage (Ostrom et al. 1999, Hess et al. 2007). Highlighting the importance of water availability as an ES, we developed a "Water Use Saved" (WUS) indicator as a proxy. We assumed that water usage varied with crop water irrigation and that lower usage indicates the lowest irrigation data. We also assumed that by reducing water use, farmers not only saved money but also benefited from more efficient human/environmental resource management. The water requirement for each start-up was calculated, and then as suggested by E. Ostrom protocol, WUS was calculated as follows:

$$(1)\ \text{WUS}_i = (\text{WU}\,max - \text{WU}i) \text{ x } 0.1$$

where WUSi is water use saved (m3), WUi is water use by a start-up project i and WUmax is the highest water use recorded among the start-ups participating in the study. The quantity of water used by each start-up was estimated using the business plans, where each start-up declared cultivated crops and extensions. The obtained value was further multiplied by 0.1 for computational convenience.

Finally, we evaluated two cultural services: job opportunities and start-up cooperation, which could enhance opportunities such as saving money by sharing materials cooperatively. Job opportunities data were obtained from each start-up's business plan. We defined four ranges of job security: (a) 1 to 3 workers employed; (b) 3 to 6; (c) 6 to 10 and (d) more than ten people employed. The start-ups' cooperation within OpenAgri different projects, e.g., sharing the working force and/or materials or using the same selling systems, was evaluated from data declared in the business plans or which emerged in the first two years of the project.

### 3.6 Data collection

Data were collected from November 2017 to March 2019 – concurrent with the OpenAgri project. Data were collected using two sources. First, we had access to the business plans presented by each start-up during the public selection process. As official documents, this source provided economic data for each project. Second, we followed the selected start-ups by actively participating in debates and reunions with the representative of each of them. This informal participation was helpful to understand the actual and real state of action of each project, and to collect data about management organisation.

To formalise and track collected data, we prepared a short questionnaire that we sent to each start-up. The questionnaire had three sections: (1) the economic dimension, i.e. asking the aimed economic turn-over and the employed force labour; (2) the environmental dimension, useful to understand ES contribution, i.e. cultivated species, required amount of water, type of agronomic management (organic or conventional); and, (3) the socio-relational dimension, to understand the start-ups' cooperation levels and the potential for conducting activities in addition to food production, i.e., recreational and cultural activities.

We then compared the data obtained from the business plans and the questionnaire. Assuming the questionnaire to be more accurate and up-to-date, we used this data for our study. In cases of incomplete responses, we assumed the data and information presented in the business plans.

To estimate the ES provided by the ecological requalification of the area, we built an internal database, with a realistic hypothesis of trees – species and numbers – that will be in the area. The database of the implant was the input for the I-Tree model simulation.

### 3.7 Pareto Front algorithm and ES performance

The selected indicators were useful to understand the relation between the ES provided and economical production, as well as to understand possible ES enhancing strategies. To answer the central questions of the study, we used the Pareto Frontiers algorithm to highlight ES trade-offs and to show which start-up was able to enhance ES and incomes simultaneously. The Pareto front algorithm is a tool widely used for selecting the best theoretical scenarios based on a large number of combinations of tested factors (Lafond et al. 2017). The Pareto front algorithm subsets groups of scenarios which dominate others by maximising or minimising multiple factors. These theoretical optimal scenarios form a "front" on which one criterion cannot improve without deteriorating the others (Pardalos et al. 2008). In this study, we kept the conceptual idea of the Pareto front algorithm, applying it to real data in order to explore putative trade-offs and synergies within the set of eight start-ups (Table X.1). By doing so, we aimed at identifying the best "performing" start-ups, i.e. those combining maximised levels of indicators. The indicators studied were assumed to be equally essential. Consequently, we did not set any weightage on the indicators studied when executing the Pareto analysis. The computed Pareto fronts were qualified as "Pareto optimal cluster" for the group of plots maximising the levels of indicators (Figure X.3).

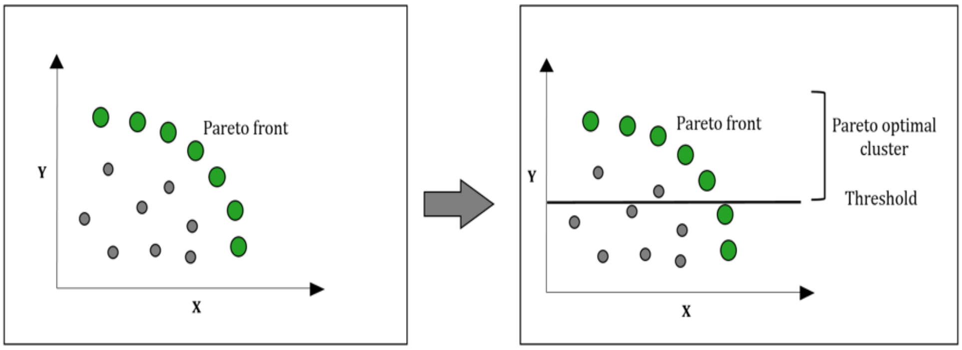


**Fig. X.3** Conceptual framework using the Pareto Frontiers algorithm. Pareto analysis conceptual scheme illustrated for two objectives (X and Y indicators). The threshold splits the cluster in two: (i) below the threshold "Pareto front" and (ii) above the threshold "Pareto optimal cluster." Each dot represents a start-up, and the green colour is the Pareto front and in grey are the non-Pareto Front (Andreotti et al., 2018)

A threshold was taken into consideration, corresponding to the last three years' average monetary value production of all the farms in Regione Lombardia (ISTAT, 2018), which amounts to 108,823 €/year (approx. USD 120,745 per year). That value is by far the highest in Italy, with marked differences from North Milan. To the South: in the same period, the farms in Molise have an average production of 11,904 €/year (approx. USD 13,208 per year). Moreover, to better explore the results of the Pareto front algorithm, a Principal Component Analysis (PCA) was performed. The Pareto analysis and the PCA were carried out using R 2.13.0 with the packages Multiple Criteria Organization (MCO) and psych (Mersmann, 2014; Revelle, 2017).

The OpenAgri project also provided the opportunity for requalification of the ecological state of the area. Indeed, in addition to the creation of a food start-up incubator, the project's other goal was to create a net of living fences with tree rows and living hedges. The objectives of the net were: (i) better link the project area with the surrounding environment; (ii) improve the provision of ecosystem services; and (iii) naturally divide and define each field between the start-ups. Therefore, in our study, we quantify the ES provided by this agroecological net.

Following the project guidelines, we assumed a total area dedicated to the agroecological net of about 1.5 hectares, planted with different plant species. Since the project was ongoing at the time of writing, we created a database to be used for simulation of the ES resulting from the agroecological requalification. The database counts 3,287 trees and shrubs, covering an area of 1.6 hectares with a leaf area of 4.475 hectares, composed of a mix of native and exotic tree species, to ensure high biodiversity and minimise the overall impact or destruction by species-specific insects or diseases. Dominant species in the database are typical of the existing landscape in the area: *Crataegus monogyna, Salix campestre, Morus alba,* and *Acer campestre.*

For the simulation of the ES provided by trees and shrubs, we assumed an initial height of plant between 0.5 and 2 meters and a diameter between 3 and 5 cm. Using these parameters, we applied the I-Tree Eco (Nowak and Crane 2000) model to the database to estimate provided ES. The model uses the database, with the add of local hourly air pollution and meteorological data, to quantify urban forest structure and provided ES (Nowak and Crane 2000). In this study, we focused our attention on the following regulating ES:

*Air Pollution Removal*

As air quality is highly important for human health, and many urban areas have a bad quality, it is clear that urban vegetation can play a crucial role in assuring a better air quality by removing pollutants. In this study, thanks to I-Tree Eco, pollution removal was calculated for ozone, sulfur dioxide, nitrogen dioxide, carbon monoxide and PM2.5 (particulate matter < 2.5 microns). I-Tree works estimating air pollution removal quantities calculating hourly tree-canopy resistances for ozone and sulfur and nitrogen dioxides, based on a hybrid of big-leaf and multi-layer canopy deposition models (Baldocchi 1988; Baldocchi et al. 1987). Regarding PM 2.5, trees remove them when particulate matter lays on leaf surfaces (Nowak et al. 2013). Pollution removal by the agroecological net in the OpenAgri area was estimated using the built database and most recent pollution and weather data available, which are taken from Linate Airport weather station, close to the area.

*Carbon Storage and Sequestration*

Vegetation is able to sequester and store carbon in its tissue, thus lowering the level of carbon dioxide present in the atmosphere. In this study, the carbon storage evaluation derived from the biomass of each tree, calculated using equations from the literature in I-Tree Eco (Nowak and Crane, 2000) and measured tree data, obtained from the available database. Carbon storage and carbon sequestration values were based on customised local carbon values. For this study, values were calculated based on a fixed value of USD 174 per metric ton, set as a current standard by I-Tree software.

*Oxygen Production*

As well as sequestering and storing carbon, trees and shrubs produces oxygen. The annual oxygen production of the vegetation is directly related to the amount of carbon sequestered by each tree, which is tied to the accumulation of tree biomass. The amount of oxygen produced derived from carbon sequestration based on atomic weights: net O2 release(kg/yr) = net C sequestration (kg/yr) × 32/12 (i-Tree report).

### 3.8 Trade-off analysis

The trade-offs analysis indicated which start-up projects belonged (True) or did not (False) to the Pareto optimal cluster ("Belong to Pareto front" column) (Table X.3) and if a start-up project was above the first production threshold ("Over the first production threshold" column) (Table X.3). In general, there were no clear trade-offs or synergetic patterns between the ES indicators for the eight start-ups in the Pareto algorithm results or the principal components analysis (Figure X.4). On the other hand, we obtained clear clusters of start-up projects, which can belong, or not, to the optimal ones, meanwhile reaching the fixed threshold of economic turn-over.

**Table X.3** ES provision and threshold by OpenAgri start-up

| **Start-up** | **First production** | **Secondary production** | **Water used saved (WUS)** | **Pollinator dependence** | **Job opportunities** | **Start-up cooperation** | **Belongs to Pareto front** | **Over the first production threshold** |
|---|---|---|---|---|---|---|---|---|
| 1. Start-up 1 | 15.0 | 0 | 3.75 | 0 | 3 | 0 | True | True |
| 2. Start-up 2 | 14.5 | 7.75 | 0 | 3 | 6 | 0 | True | True |
| 3. Start-up 3 | 15.0 | 0 | 6.75 | 0 | 6 | 4 | True | True |
| 4. Start-up 4 | 4.8 | 0 | 0.55 | 3 | 6 | 0 | False | False |
| 5. Start-up 5 | 4.1 | 1.8 | 2.75 | 0 | 3 | 0 | False | False |
| 6. Start-up 6 | 0.5 | 0.51 | 0.25 | 2 | 6 | 8 | True | False |
| 7. Start-up 7 | 12.4 | 0 | 1.25 | 3 | 6 | 4 | True | True |
| 8. Start-up 8 | 3.6 | 0 | 3.12 | 3 | 10 | 6 | True | False |

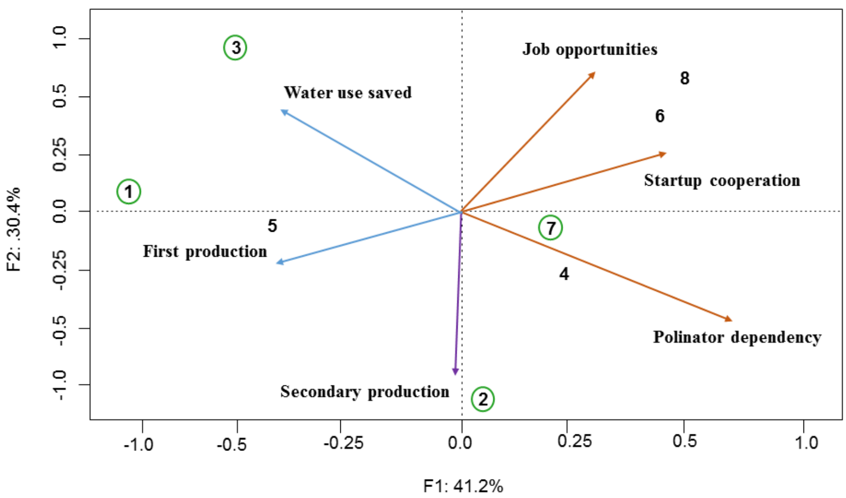


**Fig. X.4:** Principal Component Analysis of the studied ES and OpenAgri start-ups. Principal Component Analysis of the studied ES and OpenAgri start-ups (n° in table 2). The green circles highlight the start-ups belonging to the Pareto optimal cluster above the primary production threshold.  Each number corresponds to each singular start-up.

### 3.8.1 Trade-offs analysis results

Table 3 shows the findings of the eight start-ups analysed using both Pareto algorithm and the first production threshold. Only four start-ups produced more than the fixed threshold and were classified in the Pareto optimal cluster, meaning a simultaneous and positive performance in the provision of both ES and financial results. The Pareto front algorithms classified six start-ups in the Pareto optimal cluster. Using the established production threshold (ISTAT, 2018), the optimisation deleted two of the six start-ups of Pareto top cluster. Regarding secondary production and pollinator dependence, the situation was not so clear as the start-ups could not have secondary production for diversification and/or crops that depend on pollination. For the Water Use Saved (WUS) indicator, differences were observed between the Pareto optimal cluster and no Pareto optimal clusters: for example, start-up #3 (Table 2) did not require water for its cultivation of wildflowers. Cultural services related to job opportunity guarantees from three to ten jobs for Pareto optimal clusters or not.

On the other hand, the first production threshold assesses the possibility - credibility - for the start-up to create job opportunities. Based on this analysis, start-up #8, even if it produced the highest number of job opportunities (ten job opportunities), it would be under the fixed threshold, therefore not qualifying for the optimal cluster. While start-up #1, which offered the lowest number of job opportunities (three job opportunities), was classified in the Pareto optimal cluster and above the first production threshold.

We then combined the results from the Pareto optimal cluster with Principal Component Analysis. The first and the second axes of the Principal Component Analysis explained 41.2 and 30.4 % of the total variance of the start-up studied, respectively (Figure X.5). The Principal Component Analysis discriminated accurately between the Pareto clusters on the first axis. On the one hand, Pareto top clusters were projected on the first axis, where the first production was one of the main contributors. However, on the other hand, the non-Pareto optimal front and low-yield intermediate clusters were mainly projected on the second axis. Any explanation or further conclusion to help readers interpret this?

### 3.8.2 Ecosystem services evaluation of the semi-natural hedgerow network

*Air Pollution Removal*

I-Tree Eco has estimated that pollution removal was highest for ozone. It was estimated that trees remove 69.71 kilograms of air pollution (ozone (O3), carbon monoxide (CO), nitrogen dioxide (NO2), particulate matter less than 2.5 microns (PM2.5), and sulfur dioxide (SO2) per year with an economic value of USD 3906.

*Carbon Storage and Sequestration*

The gross sequestration of OpenAgri trees was estimated in 2.185 metric tons of carbon per year, with a value of USD 379,87. The i-Tree model estimates that fences in OpenAgri store 6.3 metric tons of carbon USD 1093. Of the species sampled, *Crataegus monogyna* stores and sequesters the most carbon: approximately 17.6% of the total carbon according to I-Tree Eco.

*Oxygen Production*

Fences in OpenAgri are estimated to produce 5.825 metric tons of oxygen per year, thanks to photosynthesis. However, if we consider the overall production of oxygen and available reserve present in the atmosphere, the contribution of plants appears modest (Broecker, 1970).

### 3.9 Key findings

The study results confirm that, in a peri-urban context, start-ups can offer and provide different and multiple ES in addition to the production of food, including regulating services – crop pollination – as well as cultural and social services. This finding demonstrates the vital contribution potential of start-ups to urban agglomerates for job opportunities and better use of resources, while promoting new interactions and networking opportunities in the peri-urban framework of the area, in an overall context of urban requalification.

Multi-criteria optimisation methods such as the Pareto front algorithm were successfully applied and shown to be an effective method to support management decision-making processes (Lafond et al. 2017; Bugalho et al. 2016; Andreotti et al. 2018). It was, therefore, reasonable to further explore the potential of this methodology in various ecosystems, for example, in peri-urban areas, for which such an attempt could not be found in the literature.

While the OpenAgri project was still ongoing at the time of this publication, from our results, it is clear that some of the start-ups analysed in this study (Start-ups 1, 2, 3, 7) represent best projects capable of combining the provision of multiple ES, as well as economic incomes. From our analysis, we conclude this is possible because of several aspects common to each of these four start-ups: first, a solid business plan, which tends to analyse and recognise new types of products with higher margins (i.e., spirulina production), as well as new trends (i.e., wildflowers), particularly requested by urban consumers. Second, each project promotes a more limited use of resources, and it takes into account diverse sources of income as secondary production or derived by cultural and social activities. These results are reflected by the Principal Component Analysis, which highlights the potential of start-up 7 (Figure 4). Our findings highlight that a multidisciplinary approach for peri-urban start-ups is beneficial, to stay competitive in the market and to supply ecosystem services. Combining productive, social and environmental initiatives can lead to more suitable solutions to enhance the value of peri-urban ecosystems, while answering to an increasing socio-economic issue, i.e., creating new jobs.

However, we note that for some ES – such as those regarding soil quality and the water cycle – not considered in the present study, useful results require a more extended period of data collection (5 to10 years). Indeed, understanding and assessing the contribution of the project to improve the area (i.e., water cycle, air pollution removal, and several other regulating services) requires that the project is complete and that all the start-ups are working and well-established. Moreover, dealing with an area with historical problems linked to environmental pollution, the results of OpenAgri may need additional time to be visible and tangible especially for the results coming from the ecological requalification of the area. Based on the available project indication, we assumed the use of typical plant species with small-medium dimensions. The obtained results could vary if the number of plants increase and/or if the species change. It is also essential to understand that the ES provided by trees and shrubs can change during the time, also due to non-predictable factors (e.g., extreme weather events); therefore, continuous analysis of the situation should be put in place, to monitor change actively.

### 3.10 Conclusion

OpenAgri represents an optimal case study since it is a complex, yet familiar, peri-urban area, such as that found in many urban developed agglomerates, bringing environmental and socio-economic problems, as well as opportunities. Indeed, in the first three years of the project, start-ups faced significant global challenges in addressing the requalification of a lost area. Our results suggest that the requalification and the creation of start-up hubs can boost social inclusion and economic incomes, combining the provision of multiple ecosystem services and giving more value to urban agriculture, even in developed countries. However, start-ups and ecosystem services indicators should be analysed, considering a more extended time threshold in order to highlight the real economic and environmental sustainability of start-ups and the project as a whole. In this research, four out of eight start-up projects could produce more than the fixed threshold, meanwhile belong to the Pareto optimal cluster, meaning they can maximise ES provision and job opportunities. Our result depends on several factors, such as – the goodness of the business plan, - the rational use of the given resources, - the multidisciplinary approach, which allowed the start-ups to answer to the various and ever-changing requests of the local market.

Today the project is nearly concluded, and the start-ups are at the end of their training process. During the last months, the start-ups were involved in a pre-incubation process to develop their ideas and business plans. Thanks to this process, some start-ups changed their original project, adopting new strategies, in order to seize new opportunities and face unexpected problems, such as low availability of the needed amount of water to cultivate vegetables. We can thus affirm that each start-up has demonstrated a high level of resilience, being able to adapt itself to variable conditions. The requalification of the area is still ongoing too, so in the next future also local citizens will benefit from the improvements, representing a scalable example in a similar place. In developed countries, at the margin of our growing cities, we can find a multitude of places that need a requalification, thanks to urban agriculture – providing in one solution several benefits. Therefore, urban agriculture in these complex contests should not be as subsistence food staple supplier, but as a single occasion to mark a socio-economic new start and to satisfy the latest urban needs in terms of sustainability, local food supply, and territorial cohesion. OpenAgri is one of the first endeavours linking together these related topics. It serves as a potential future case of study for further analysis and represents a replicable model in other urban contexts for the redevelopment of abandoned territories.

**Acknowledgements**

This study was conducted as part of the EU Urban Innovative Action program "OpenAgri" project. We are thankful to project partners for their help and, in particular, we are grateful to each start-up that agreed to share data and information used in this study.

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# 4.Peri-urban agriculture and sustainability evaluation

This chapter presents the last activity carried out during OpenAgri project.

It shows the assessment conducted on the project start-ups, in order to evaluate their sustainability level. The study underlines the dynamic context in which peri-urban agri-food start-ups work: indeed, urban markets are witnessing a continuous growth and, in the last months, several European directives have indicated peri-urban agriculture as a potential key to promote a sustainable development, since often it takes place in neglected areas in need for requalification. To meet these challenges and to satisfy local market requests, these new enterprises have to face a challenging management and environmental path, conciliating together governance strategies and new environmental solutions. To verify the goodness of this process, we tested sustainability level of the start-ups thanks to the implementation of an international framework, to demonstrate strengths and weaknesses of each enterprises.

The following chapter has been submitted to the special issue "Sustainability and Peri-Urban Agriculture" of the MDPI's journal Land (ISSN 2073-445X), Impact Factor 2,429, and then published in April 2021 (https://doi.org/10.3390/land10040384).

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# Assessing Agri-Food Start-Ups Sustainability in Peri-Urban Agriculture Context

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**Abstract:** Latest international directives indicate the need for sustainable development, linking socio-economic and environmental aspects, to reach the goals set by Agenda 2030. In this context, peri-urban agriculture can represent the opportunity to increase cities' sustainability, improving their liveability level, fulfilling a crucial social part since it assures new sources of job opportunities and territorial requalification. This study presents a peri-urban requalification experience, conducted in Milan, Italy, where, within the European funded project OpenAgri, eight agri-food start-ups began their activities in a peri-urban area at the southern gates of the city. The study aims to assess and evaluate these start-ups' sustainability using the Sustainability Assessment of Food and Agriculture systems (SAFA), which considers four sustainability pillars: Good governance, economic resilience, environmental integrity and social well-being. The application of SAFA indicators to the eight start-ups revealed their positive aspects and some limitations, typical of some not structured enterprises. The research describes a scalable and replicable example of peri-urban agriculture's potentiality in solving environmental, social and economic issues and tests FAO's SAFA framework, which is still unexplored in this sustainability assessment context.

**Citation:** Zanzi, A.; Vaglia, V.; Spigarolo, R.; Bocchi, S. Assessing Agri-Food Start-Ups Sustainability in Peri-Urban Agriculture Context. *Land* **2021**, *10*, x. https://doi.org/10.3390/xxxxx

Academic Editor: Dr. Marta Debolini

Received: date
Accepted: date
Published: date

**Publisher's Note:** MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



**Keywords:** sustainability evaluation; peri-urban agriculture; SAFA tool; entrepreneurship

## 4.1 Introduction

### *4.1.1. Need for Sustainability*

The European Union has profoundly redefined its environmental strategies, as it proves the publication of crucial programmatic documents—Farm to Fork and European Biodiversity Strategy—and the European Green Deal definition. These strategies follow the ambitious goal of making Europe the first climate-neutral continent by 2050, affirming the vital principle of creating a "new, sustainable and inclusive growth strategy to boost the economy, improve people's health and quality of life, care for nature, and leave no one behind" [1]. Similar goals have been previously set by Agenda 2030 [2] with the definition of Sustainable Development Goals (SDGs), where food systems and agriculture cover a crucial role, especially considering goals number 11 and 13. The importance of food systems and agriculture became even more evident analysing Covid-19 pandemic impact [3], which evidenced the worldwide need for a healthy and resilient food system, vital in every possible circumstance and source to promote economic recovery and citizen well-being [4]. In particular, the future food system is described as safe, sustainable, nutritious and affordable, implementing sustainable agronomic techniques (e.g., input reduction) and increasing the cultivated lands [4]. These strategic considerations intersect with some other significant trends observed in the last years. These trends do not regard only the agri-food world, but are due to broader modifications in many social fields that reflect significant changes in the agri-food market, encompassing both consumers and producers. First of all, between consumers, environmental sustainability themes have witnessed a marked increase in interest between consumers, mostly linked to food consumption and a healthier diet [5]. The boost in demand for sustainable food has caused a consequent upgrade in the offer [6].

Moreover, a new vision of the society is emerging, namely the "green shift": This shift underlines the importance of renewable resources, effective use—and reuse—of materials, emission reduction, as well as the transition to products and services that have minor negative consequences for the climate than today [7]. Pursuing this shift and related SDGs goals could change the usual way of producing and consuming with the help of innovation and technology that could play a fundamental role in this path [8].

*4.1.2. Peri-Urban Agriculture and Current Global Challenges*

Despite this demand for global sustainability, cities and urban agglomerates continue to overgrow: In the last 30 years, cities greatly expanded [9], and the latest long-terms forecasts confirm an increase in world urbanisation—from 56,2 to 60,4% in 2030—even if it is still too early to evaluate the impact of Covid-19 on urbanisation [10]. Due to this trend, urban and peri-urban areas are losing agricultural soils, and the number of farms tends to decrease [11,12], leaving space to new suburbs or urban sprawl, with an overall degradation of natural environments [13].

In the future, agricultural landscapes could provide possible new solutions to these challenges. In particular, peri-urban agriculture (PUA) can play a crucial role in providing sustainable food to local city markets, while connecting urban and rural areas and improving dismissed areas [12]. Today, low-income populations have mostly practised PUA, with significant effects on food security [14] and socio-economic issues. Indeed, in developing countries, low-income citizens can self-obtain fresh products (e.g., vegetables and eggs), even without a stable economic income [15]. However, with the developments of cities and their total dependence on food supplies with close rural areas [16], PUA is assuming a commercial purpose too, creating new business opportunities for the enterprises related to food production, processing and distribution [17,18], also in developed countries [19]. Here, local food request goes hand in hand with socio-economic issues, since the need for urban regeneration and job opportunities, and the growing sensibility between consumers related to sustainability topics [20]. These trends are contributing to shaping new forms of PUA, marked by multi-functionality. Indeed, especially in developed countries, peri-urban farmers do not focus only on staple food production, but offer a series of services to the local community and environment, such as cultural and social opportunities, urban regeneration and aesthetic added values to surroundings [21]. In other words, PUA can provide a wide range of ecosystem services (ES), not only linked to the provision of food and other goods but also cultural and regulating ones (Figure 1).

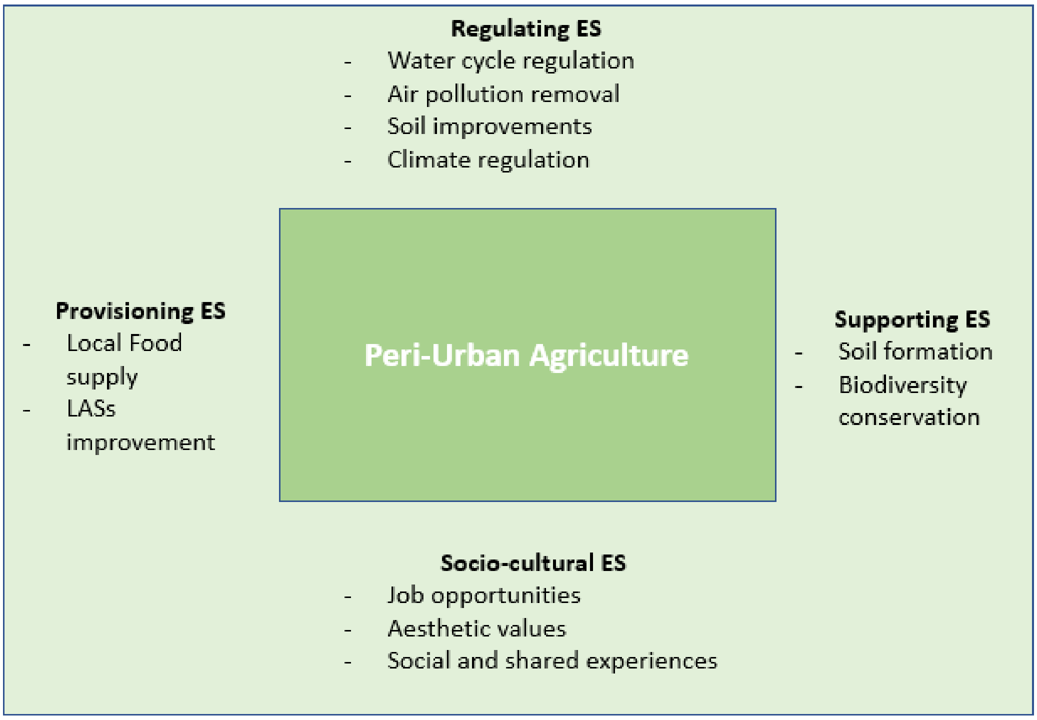



**Figure 1.** The wide range of Ecosystem services granted by peri-urban agriculture.

Among the provided ES, PUA can contribute to reshape the food supply panorama actively. Indeed, there is an increase in promoting smart and resilient activities to rethink peri-urban areas, where ecosystem restoration can provide net benefits [22]. The latest data [23] show that, in developed countries, agriculture mainly produces for the global agri-food industry, with just 20% of the products marketed locally. Even if local supply chains—e.g., direct sales and farmhouses—are already well-known, their overall impact is still limited, even if growing [24]. Different aspects are pushing this growth: (i) Urban population increase; (ii) higher demand of raw food; and (iii) more significant consumers' sensibility about sustainability, resulting in the development of local agri-food sectors, to satisfy local demands and to structure new models of short supply chains on a territorial scale, with the creation of Local Agrifood Systems (LASs). LASs can cut food supply chain, retain most local market production, and shorten the relation between growers and consumers [25]. In this view, LASs can represent an optimal solution to stimulate the requalification of peri-urban context, with PUA implementation and an overall economic, occupational, social, cultural, and environmental enhancements. However, this formula has several expressions: Indeed, it depends on territorial and environmental conditions, socio-economic context, political views, and cultural awareness.

Furthermore, the concept of "local" is ambiguous in many ways: e.g., according to United States rules [26], a good produced within 400 miles (643 km) from the place of consumption, and in any case within the borders of a state, can be defined locally. If it fits in the U.S. context, this definition is not suitable to the European one, where a product is definable as "local" if produced, processed and retailed within a defined geographical area within a 20 to 100 km radius approximately [27]. Moreover, in the EU context, there is a closer focus on the link between local production and its perceived properties (e.g., ecologically sustainable, healthy, traditional, respectful of biodiversity) [28].

This research presents a case study where the implementation of a LAS contributes to the birth of local agri-food start-ups, developing new job opportunities. Therefore, start-up incubators can shape urban and peri-urban areas' economy and provide several ES related to their activities, including providing local food supply [21].

*4.1.3. Tools and Framework for Sustainability Assessment in Agricultural Contexts*

In this dynamic context, the evaluation of the contribution of agriculture—and PUA—to sustainable development and the connected socio-economic effects has gained researchers and institutions' attentions.

FAO has defined sustainable development as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable" [29]. Sustainable development ecological, economic and social principles received universal agreement at the 1992 Earth Summit: One of the summit's significant outcomes, Agenda 21, includes a whole chapter (Chapter 14) on sustainable agriculture and rural development [30]. Today, 106 countries have National Sustainable Development Strategies and over 200 voluntary sustainability standards implemented by the food and agriculture industry. However, developing and implementing an integrated approach to analyse different sustainability dimensions in business strategies remains a significant challenge. In the latest years, to help decision-makers and stakeholders, several frameworks and tools have been developed and tested to assess and quantify the broad contributions of agriculture, with particular attention to its long-term effects. These assessments may regard several aspects, spacing from political to environmental consequences. Table 1 shows the main frameworks available in the literature.

**Table 1.** Principal frameworks used to evaluate sustainability in agriculture [31].

| Framework | Developer | Year of Publication | Focus |
|---|---|---|---|
| Sustainable Intensification Assessment Framework | Michigan State University | 2017 | Evaluation of agricultural activities and their effects |
| The Economics of Ecosystems and Biodiversity—TEEB | UNEP TEEB | 2011 | Ecosystem services assessment and quantification |
| SAFA—Sustainability Assessment of Food and Agriculture systems | FAO | 2014 | Farmer/enterprise evaluation based on four sustainability pillars |
| Sustainable Rural Livelihoods approach | CIRAD | 2019 | Rural/Family farming assessment |
| TAPE | FAO | 2019 | Evaluation of agricultural performances via agroecological indicators |
| Method to assess sustainability and resilience in farming | SOCLA—Sociedad Científica Latinoamericana de Agroecología | 2019 | Robustness, adaptability, transformability of farming systems |
| GTAE—Groupe de Travail sur les Transitions Agroécologiques | CIRAD-IRD-AgroParistech | 2017 | A framework to drive and evaluate the agroecological transition |

Other frameworks are present in literature, with a growing interest in assessing agroecological aspects [31]. As stated by [32], there is no one-size-fits-all solution in this kind of assessment, with the consequent needs to choose the most suitable framework for the context, as it emerges in literature, where several studies could help understand the most suitable choice [33–35].

#### 4.1.4. Objectives

Since the current high interest around the topics, the present study aims to assess the sustainability level in a peri-urban agriculture context, analysing a series of agri-food enterprises involved in a peri-urban requalification project—the OpenAgri project and its start-ups—in Milan, Italy, where a LAS is forming. The sustainability assessment is conducted applying the FAO's SAFA framework, thus representing an interesting test for this methodology since it is the first example conducted in a peri-urban agricultural area.

### 4.2. Materials and Methods

#### 4.2.1. Case Study

To conduct the present research, we focused on a particular case of study, the OpenAgri project. This project has some peculiarities, mixing agriculture, entrepreneurship and agri-food system. The project was funded by the EU Urban Innovative Action program, which promotes innovative solutions to rethink and requalify life in urban and peri-urban areas across Europe. Following the legacy of Expo 2015 and the challenges set in the Milan Urban Food Policy Pact (MUFPP) [36], Milan council and other 15 organisations gained the UIA fund after having proposed the requalification of a peri-urban area and its neglected socio-economic and environmental background, implementing a sustainable peri-urban agriculture hub. For the first time, agriculture has been recognised as a possible solution to socio-economic issues in developed and urbanised areas, equating its role to other urban requalification solutions.

OpenAgri main goal is to requalify a ruined peri-urban area—close to Vettabbia river—located in the south part of the city, at the fringe zone of the urban agglomerate, where fields progressively left space to uncontrolled urban sprawl, just before the Parco Agricolo Sud, the major European agri-area with its 47,000 hectares. The area—35 ha of extension—has a long history and tradition, encompassing medieval abbey—(Chiaravalle), farmstead, and fields. The area has represented a traditional agricultural hub for centuries, at the city's gate, then converted into an industrial and residential suburb in the last fifty years. Transformations have occurred in the area, resulting in an overall environmental degradation, as well as in the local inhabitants' socio-economic tissue, causing the abandonment of the fields and the local farms' crisis.

A requalification is thus needed, involving not only environmental aspects but socio-economic ones too. Indeed, even if Milan is recognised as the economic capital of Italy, situated in the region with higher GDP [37], there is a growing social malaise, in particular with the youngsters: The youth unemployment rate is high (28.6%), and the percentage of NEETs, defined as young population (aged 15–29) not engaged in education, employment, or training, in the metropolitan area is at 17.6%, [38] even before Covid-19 impact.

Furthermore, analysing the consumption data, Milan depends on food provisioning from other areas, having witnessed a widespread land reconversion from agriculture to more profitable businesses. This trend follows the National and European one: In Italy, agricultural production and workforce are declining, with a loss of more than 100,000 people employed in the period 2013–2015 [39]; while in Europe, there has been a loss of 17,5% agricultural jobs in the last ten years [40].

In this context, OpenAgri project wants to requalify this peri-urban area, implementing an open innovation hub on peri-urban agriculture and fostering social inclusion, jobs, and skills creation along the food supply chain, while increasing the level of resilience and sustainability of the city [38]. The project lays on two main pillars: An overall requalification of the area, including the abbey, extensive environmental remediation, and the revitalisation of the local socio-economic tissue. Indeed, after a public bid, eight start-ups were selected to work on OpenAgri fields. These start-ups are focused on food production, and their activity ranges from flowers production and retail to horticulture and seed production, following the goals set by MUFPP: To develop a sustainable food system delivering healthy and accessible food, reducing its waste; to avoid biodiversity loss, making urban food systems more inclusive, resilient, safe, and diverse. OpenAgri, linking together environmental remediation, agri-food start-ups and job creation, represents a multidisciplinary project able to council economic outcomes and peri-urban requalification, serving as a possible example in other similar peri-urban neglected areas.

#### 4.2.2. Data Collection

OpenAgri project started in 2017, with its finish in 2020. For the environmental remediation of the fields and to promote farming activities, the project launched a public bid to assign arable lands and reward innovative activities in the area. The bid's scope was to select a group of start-ups with an agri-food focus to assign 35-ha to improve the area's requalification creating the first attempt of LAS. Fifty start-ups responded to the bid. The selection process evaluated fixed criteria, such as previous experiences and background, surface needs, and in-need categories.

Moreover, each participating start-up had to present a complete business plan to show the proposal's aims, scope, and sustainability. Rewarding points were possible demonstrating synergies between start-ups and proponents' age (to be under 40 years-old was considered a plus). Twenty-seven projects passed the first formal evaluation process, and eighteen were admitted to the fields' cultivation, with a further reduction to eight start-ups, due to merging of some realities and the quitting of some other subjects. These eight projects were the object of our study, reported in Table 2. Data relatively to each start-up were collected during 2019–2020, concurrently with the OpenAgri project. Sources of the data were the business plans presented during the bid. These documents provided us with a clear view of each start-up, clarifying goals and perspectives. This in-deep evaluation has been fundamental to assess and understand each involved project's consistency, analysing the five years of development in the business plan. Another data source was a questionnaire (Appendix A) that we prepared and spread to the start-ups. The questionnaire's main goal was to have real-time feedback about the progress done and obtain further information on several aspects not investigated in the business plan. The questionnaire had three parts: (i) The economic dimension, asking the confirmation of what previously planned in the business plan and the employed workforce; (ii) the environmental aspects, in the light of the environmental particularities of the fields (a limitation in water availability) and related ES provided; (iii) the social dimension, to analyse start-up cooperation. Other researches investigate the relationship between ES and job opportunities with Pareto algorithm analysis [41]. These data were implemented into sustainability assessment tool as input. The indicators considered were the same for all the start-ups, with a distinction, since two of the eight start-ups do not use directly arable land (Figure 2) for their activities. Indeed, start-ups 1 produce spirulina algae in a water-based system, and start-up 3 commercialises flowers for the local retail market.

In addiction, our active involvement in OpenAgri took us to participate in start-ups reunions, evaluating each project's progress compared to what described in the business plan presented at the beginning of the project.

**Table 2.** List of start-ups working in the OpenAgri area and description of activities.

| Number Start-Up | Activities and Target Market |
|---|---|
| **Start-up 1** | Spirulina algae production |
| **Start-up 2** | Agri-technologies for crops and vegetable production |
| **Start-up 3** | Flower bouquet production and retail |
| **Start-up 4** | Wheat cultivation for local bakers |
| **Start-up 5** | Snail production |
| **Start-up 6** | Seed production for local organic farmers |
| **Start-up 7** | Wildflowers and edible plants production |
| **Start-up 8** | Old cereal, hemp and Paulownia sp. Cultivation for the local market |

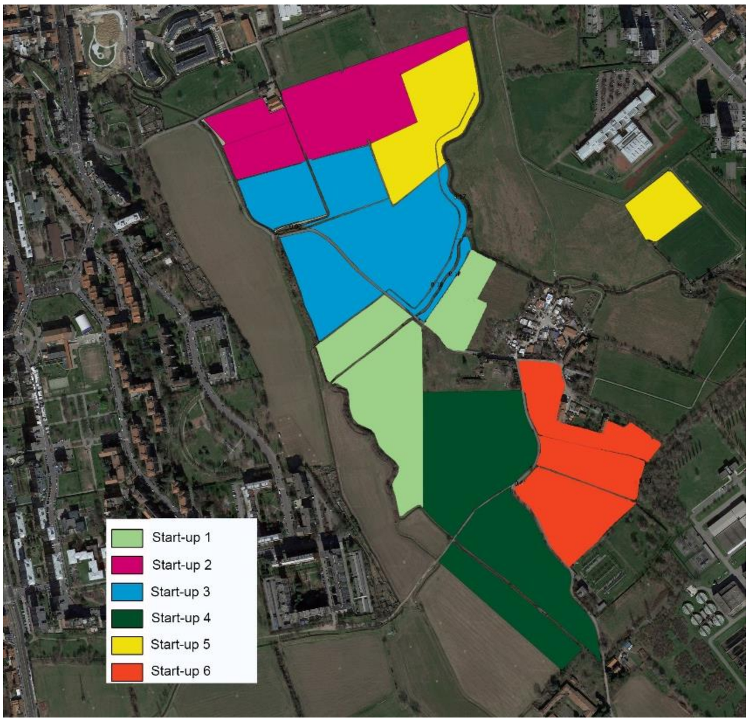



**Figure 2.** The sixth start-up divide in fields. Two start-ups (no. 1 and 3) do not directly cultivate fields, so they are not relevant on the map.

*4.2.3. SAFA Conceptualisation, Selection, and Application*

The collected data and the derived database were used as input to conduct a sustainability assessment. Among the several frameworks available, we decided to use the Sustainability Assessment of Food and Agriculture systems (SAFA). This decision was due to several aspects considering literature research articles that used and supported the method [42–44] and compared it with others [45, 46]. The SAFA framework has been developed by FAO, following a long path and delivering a robust and peer-reviewed methodology [47]. Moreover, differently from other similar systems, SAFA is not focused on the evaluation of a product—this approach would be close to a Life Cycle Assessment (LCA)—but on the overall evaluation of an enterprise, being adaptable to different contexts and size of evaluation. SAFA approach is thus focused on the enterprise and its role in the supply chain, not only with interest in environmental inputs and outputs, as it is typical in LCA, but also on governance and well-being components. The assessment depends on four categories of evaluation: (i) Good governance, (ii) environmental integrity, (iii) economic resilience, and (iv) social well-being (Figure 3).


**Figure 3.** According to the Sustainability Assessment of Food and Agriculture systems (SAFA) approach, sustainability assessment depends on these four categories of evaluation. Source: SAFA Guidelines.

Therefore, SAFA is a holistic framework for assessing a specific subject's sustainability in each aspect considered, thus representing a benchmark capable of assessing trade-offs and synergies between all sustainability faces [47]. The framework's organisation reflects the diverse sustainability dimensions, considering the four pillars' division (Figure 3) analysed, using 21 themes, 58 sub-themes, and 116 indicators (Figure 4).


**Figure 4.** SAFA structure and division into themes, sub-themes and indicators. Source: SAFA guideline.

The themes are related to 21 sustainability core issues. These themes focus on universal sustainability goals and encompass the four pillars previously described (Figure 3).

The themes used to design the sustainability path declines with sub-themes related to sustainability specific objective. SAFA sets 58 sub-themes, definable as an individual issue within SAFA themes. Indicators are measurable criteria to track sustainable performance for sub-themes and represent a standardised metric to guide sustainability assessment. For each indicator, SAFA sets the benchmark level, helping the user conduct the assessment and quickly understand if it is acceptable or below the needed level. Each indicator has an associated rating scale, from best to unacceptable. Each value is also associated with colour to quickly interpret the graphical result associated with each indicator's percentage scores during the analysis. Table 3 reassume the categories of performance associated with colours and percentage scores.

**Table 3.** Categories of performance associated with colours and percentage scores. Source information: SAFA Guidelines.

| Performance | Colour | Percentage Scores |
|---|---|---|
| **Best** | Dark green | 80–100% |
| **Good** | Light green | 60–80% |
| **Moderate** | Yellow | 40–60% |
| **Limited** | Orange | 20–40% |
| **Unacceptable** | Red | 0–20% |

It is important to note that, in order to have a balanced evaluation, each indicator has a weight for each sub-theme level. In particular, each sub-theme has the same weight as well as each indicator within the sub-theme. That means that the weight is distributed equally between the indicators: If there are two indicators in a sub-theme, the mean must be one of the two scores, which have equal weight in the overall sub-theme score.

In our research, we decided to conduct the sustainability assessment on a tailored selection of the SAFA indicators. Out of the 116 available ones, we selected 69 indicators belonging to all four dimensions. This selection was due to the characteristics of OpenAgri project and its start-ups, which were suitable for some indicators, but not for others (e.g., some economic resilience indicators and social well-being are suitable for developing countries). The assessment's adaptability is a typical peculiarity of SAFA methodology compared to other frameworks, as reported in SAFA guidelines. It is possible to use part or total of the indicators in their default form or in an assessor's tailored made one.

The assessment is conducted through the SAFA Tool software, which is a free, open-source application developed by FAO to implement SAFA assessment via its guidelines. The software, user-friendly, drives the user during the assessment procedure in four consecutive steps: Mapping, contextualisation, indicators and reporting.

The analysed start-ups have a separate assessment, each describing a similar context—OpenAgri project—in which the enterprises are operating and then specifying each start-up's particular characteristics, using the information obtained from the business plans gained from the questionnaires.

Data quality is thus considered high by SAFA since data are primary and specifically collected. Therefore, SAFA can assign a different weight to each indicator depending on data availability, as is shown in Table 4. In our case study, the SAFA Tool assigned the maximum score—3 points—to each indicator.

**Table 4.** Accuracy score depends on data reliability. Source information: SAFA Guidelines.

| Data Quality per Indicator | Criteria | Accuracy Score |
|---|---|---|
| High-Quality Data | Is the data current? Maximum 1–2 years old. | 3 |
| | Is it primary data collected directly for SAFA? | |
| | Is its primary data from a previous third-party audit or sustainability framework? | |
| Moderate Quality Data | Is it primary data older than two years but considered still reliable? | 2 |
| | Is it secondary data? | |
| Low-Quality Data | Is it primary data older than five years? | 1 |
| | Are data estimations or proxy? | |

If no data were available or the indicator was not considered suitable for our assessment, following SAFA guidelines, we used the "yellow grade", thus indicating neutrality in that specific indicator and not influencing the overall assessment. The four separate steps lead to the Performance Report, a descriptive and analytic review of each analysed start-up's sustainability.

**4.3 Results**

Each indicator's score was reported (Appendix B) into Safa Tool software, which weighted the used indicators and gave us the following graphical results for each analysed start-up. The graphical results appear as a spider graph and bar chart giving the same information. In order to be more precise, we will show for each start-up the spider graph results.

- Start-up 1:

The first start-up produces spirulina, an alga used in the food industry. The production process involves a water-based industrial plan: Therefore, the start-up does not directly cultivate OpenAgri fields. This situation reveals the lower grades regarding soil, land, and biodiversity conservation, which the start-up does not primarily consider. Instead, the start-up shows the robustness of its business plan, with high grades in most of the indicators. Figure 5 shows SAFA results related to the start-up.

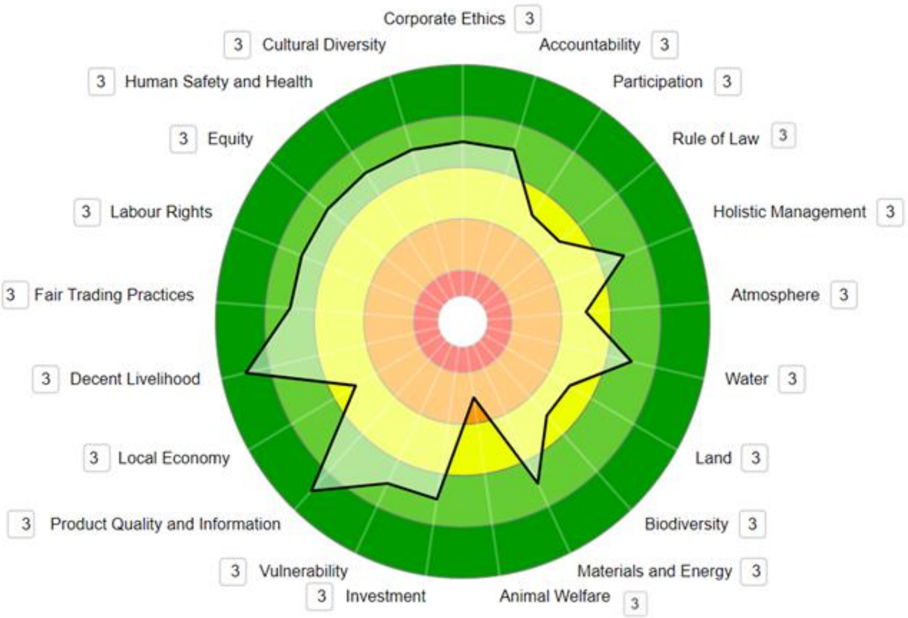



**Figure 5.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. Low scores regarding soil indicators are due to the not-cultivation of land.

- Start-up 2:

The second start-up core business is twofold. Figure 6 shows SAFA results related to the activities. The cultivation of vegetables and horticultural products facilitates technological and sustainable production techniques in greenhouses. This technological approach results in good economic and management performances, while some environmental indicators—such as water usage and ecosystem connectivity—should be improved.

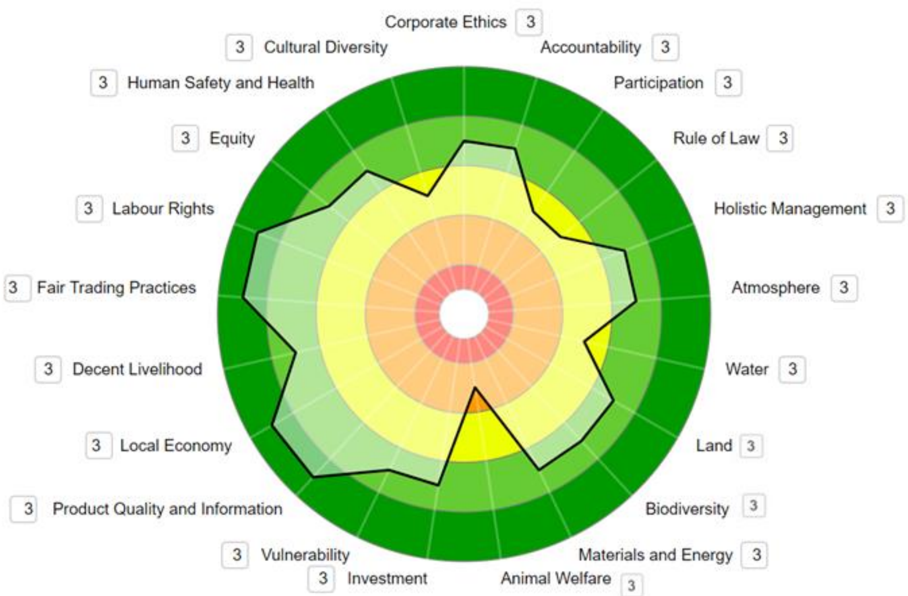


**Figure 6.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. High scores in environmental and management indicators are due to the deep implementation of digital production tools.

- Start-up 3:

As the first start-up, this one is not directly cultivating the area. Instead, the start-up's core business is to prepare and deliver wildflower bouquets, following one of the latest urban market trends. Therefore, environmental indicators received lower grades, even considering the dependence on foreign suppliers and the related footprint. A robust commercial approach and innovative business solution—bouquets flower as weekly service to subscribers—produce positive economic and management feedback, considering the gender equity shown by the enterprise, whose founders and leaders are women. Figure 7 shows SAFA results related to the activities

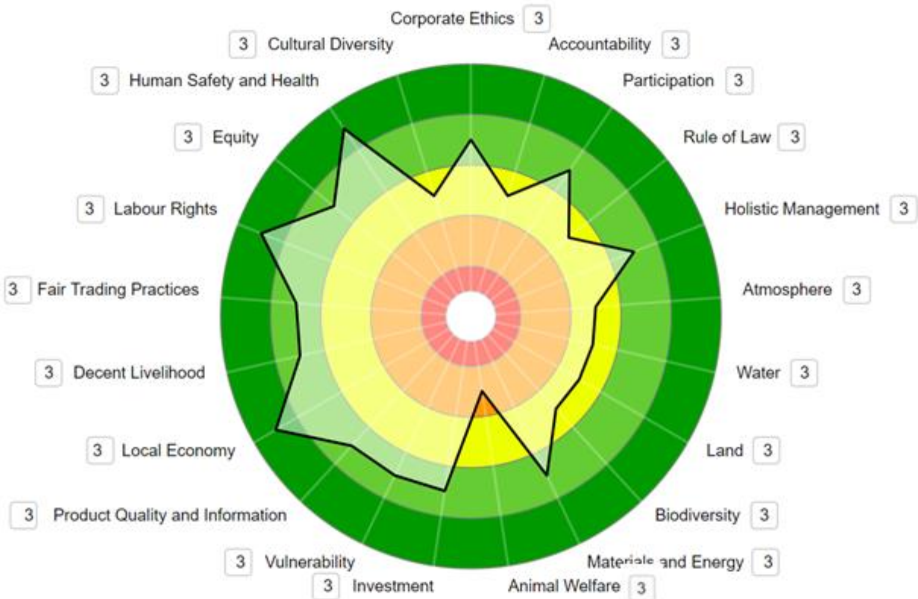



**Figure 7.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. Yellow grades linked to soil indicators show the limited consideration of the topic, while green colour demonstrates the goodness of the management plan.

- Start-up 4:

The start-up mission is to innovate the bread supply chain. The start-up plans to create collaborations with local bakers and to introduce in OpenAgri fields social cultivation of cereal, followed by educational classes to learn bakery processes. The close relationship with local stakeholders generates positive feedback in local economic indicators, while other management aspects—e.g., accountability—seem to be neglected. Figure 8 shows SAFA results related to start-up activities.

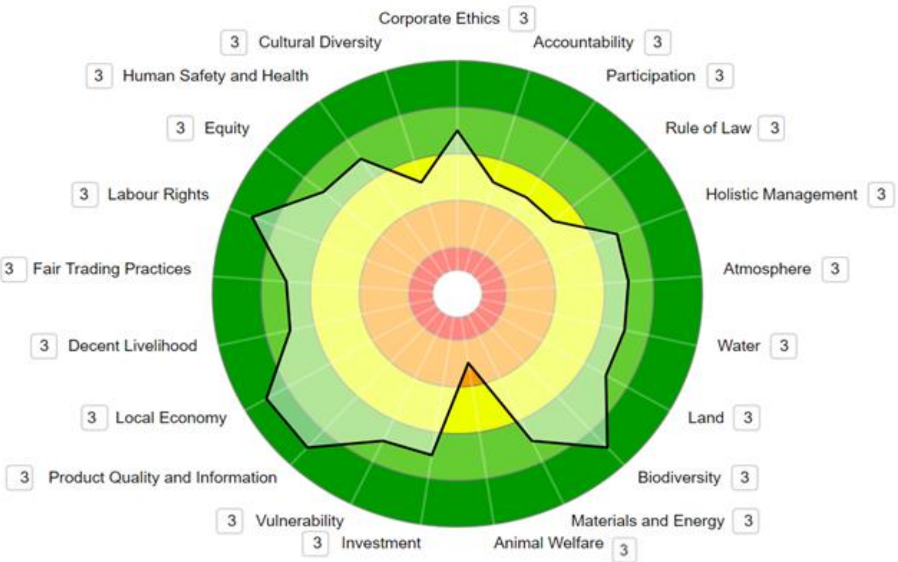



**Figure 8.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. The implementation of old varieties leads to a high score in biodiversity indicators, and the involvement of local community fosters green colour related to local economy indicators.

- Start-up 5:

The start-up goal is to cultivate snail applying automatic processes and techniques. Figure 9 shows SAFA results related to start-up activities. Their overall positive environmental evaluation and good feedback regarding employment treatments since high automation levels result in raised workplace safety.

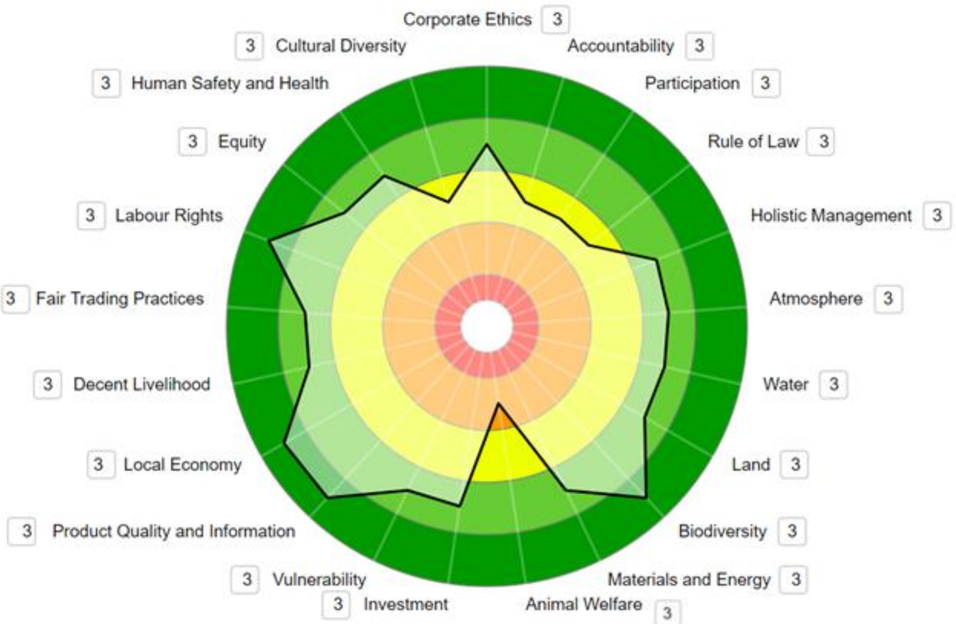



**Figure 9.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table

3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable.

- Start-up 6:

This start-up shows an overall high sustainability grade , as it emerges from Figure 10, showing SAFA results. Indeed, the start-up focused on organic cultivation and seed production for local farmers. That leads to the conservation and promotion of ancient cereal variety, a minimal environmental impact due to the absence of agrochemical inputs and the rigorous certification process.

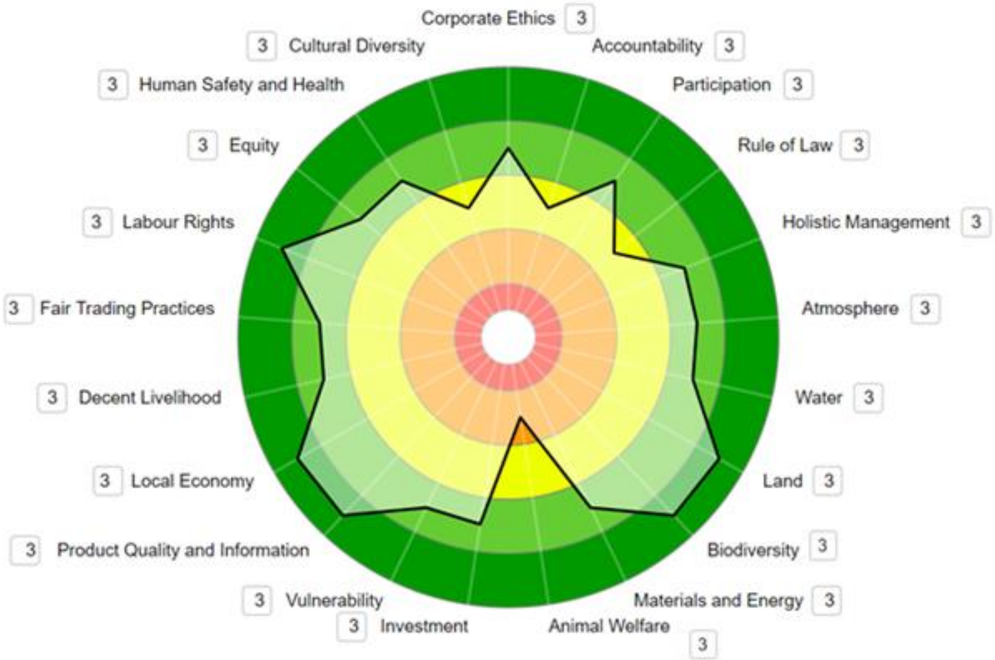
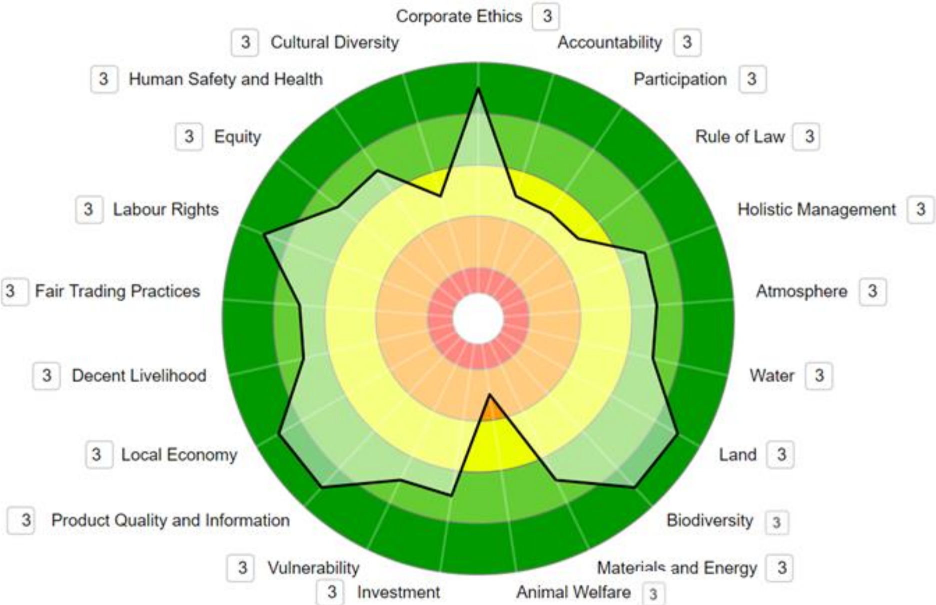



**Figure 10.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. The organic management and involvement of local stake-holders generate high level of sustainability, with several green scores.

- Start-up 7:

The start-up focuses its activity on wildflowers production and edible plants cultivation. The business plan is solid and follows the increasing demands and trends of these goods in urban markets. Moreover, the start-up follows organic production management, reducing chemicals consumption and gaining an overall positive assessment. Figure 11 shows SAFA results related to start-up activities.

**Figure 11.** SAFA




assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. The presented business plan resulted in overall high scores linked to environmental and management indicators, while limited scores were obtained regarding social participation and stake-holder involvement.

- Start-up 8:

The last start-up has as core business the production of ancient varieties of cereal and the cultivation of Canapa as a fibre source. Moreover, collaborating with a Peruvian non-profit organisation, the start-up aims at testing the cultivation of exotic species, such as Quinoa (*Chenopodium quinoa*) and Canahua (*Chenopodium pallidicaule*) well-known for their nutritional values. These goals cause marked results in environmental indicators, as well as good performances in corporate ethics. Figure 12 shows SAFA results related to start-up activities.

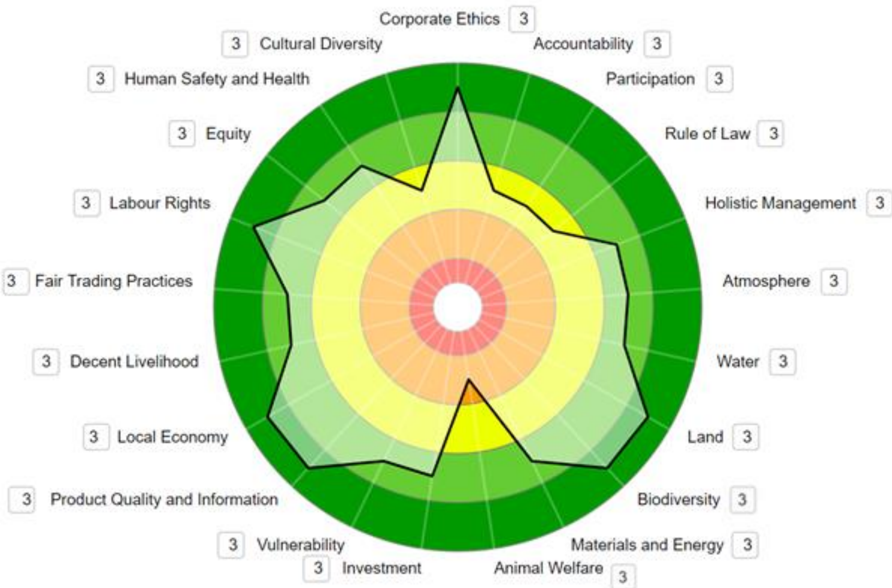


**Figure 12.** SAFA assessment result of the start-up as spider graph. The number near indicators suggest the data quality according to Table 4, and also, the colour in the circles represent the range score. As reported in Table 3, the colour means the performance score: Dark green: Best; light green: Good; yellow: Moderate; orange: Limited; red: Unacceptable. Like other start-ups, the implementation of various species leads to a high score in environmental indicators, here even higher due to the introduction of exotic species valuable to the local market.

### 4.4 Discussion

The assessment revealed each start-up's peculiar characteristics, underlining strengths and weaknesses in their path to reach sustainability. Moreover, the overall process helped understand the SAFA approach: The framework, which till now has mainly used in developing countries [48–53], confirmed its wide and known adaptability since it leaves a high grade of freedom to the assessor, that is in charge of selecting the indicators, the related questions, replies and final scores. However, this openness revealed as a double-edged sword: The assessor's subjectivity may cause misjudgements or not homogeneous grades, especially in contexts where there are no fixed benchmarks useful for grade calibration. In our case study—a peri-urban area in a developed country subjected to requalification supported by European funds—the risk of a subjective assessment was reduced applying the rigid structure of the Italian legislative context and the OpenAgri project rules: Indeed, the availability of detailed documents and business plans was fundamental to avoid possible partial scores.

All the evaluated start-ups demonstrated a high sustainability level in all four pillars—environmental, economic, social, and governance. However, several key points emerged. First of all, all the enterprises contribute to requalify a dismissed area, employing people and assuring a net land gain and ES provision. This stated fact significantly contributes to the positive evaluation of the start-ups. As stated by [41, 54], the OpenAgri start-ups have a robust multifunctional approach that maximises job creation and ES provision.

Nevertheless, the overall project is at a new-born stage and, consequently, the start-ups. Some internal policies and rules are not present and codified yet; others—such as environmental certifications and management structures—are typical of more structured realities and therefore not suitable for the case study. Despite these lacks in defining the internal policies, all the start-ups manage to improve the environmental, social and economic tissue in which they work. These considerations led to positive scores in several indicators, according to the Table 3 criteria, especially in environmental sub-theme, assigning "light green" grade, since the maximum score level "dark green" is associated with entities that conjugate practical experience with written policies.

These considerations are valid for the economical and good governance pillars too: Indeed, the start-ups have no clear and stated written policies or regulations regarding financial risks or governance audit; despite this lack, they are anyhow respecting principles in the practices, e.g., stipulating voluntary insurances and involving local stakeholders. Regarding stakeholder involvement and relations, we considered each start-up as a stakeholder to the others, meaning that the enterprises more open to collaboration (e.g., start-up 3) received a higher evaluation in the related indicators. Whereas, it emerged that for some indicators, the start-ups should improve their performances: e.g., they lack transparency and communications, since the only means used is the social media, with no impartial control on the released information.

Regarding the assessment of social aspects, it is essential to highlight that, being the evaluation conducted on a European project carried out in Italy, most of the indicators received a high grade since all the start-ups are fully compliant with national laws. Indeed, in developed countries, it is stated and clear that no child labour or any illegal workforce should be present: These indicators may be more helpful in developing countries with minor restrictions in the workforce. Other examples can regard the health indicators: Operating in a country where healthcare is mainly public and almost free, healthcare access indicators saw the highest grade to all the enterprise. However, because of this healthcare availability, the start-ups did not evaluate as essential the need for further private healthcare assistance for their employees, therefore receiving low evaluation in the related indicator.

It is also noticeable that, in a developed context, only a few of the start-ups have a gender equality policy and reality: Out of the eight enterprises, only start-up n.3 is founded and managed by women, while start-up n.6 has two women as cofounders. Nevertheless, it should anyhow highlighted the social role of the start-ups: Acting in a context where unemployment rates and NEETs are increasing, OpenAgri follows its motto "new skills for new jobs", hosting the start-ups in an attempt at territorial requalification: Observants to this, the start-ups employ local vulnerable people, as youngsters and foreigners, actively contributing to the socio-economic improvement.

Other essential considerations emerged analysing the SAFA environmental indicators considered. Out of the eight start-ups, two have as core business agricultural processes that do not involve open field cultivation: Start-up 1 focuses on spirulina production, which occurs in a water-based implant, while start-up n.3 is trading flower bouquets. The remaining six enterprises cultivate the 35-ha fields, mainly following organic management for the assessment that let us considers soil indicators only for these six start-ups. The different indicators considered did not affect each start-up's overall evaluation. The comparison between values and results obtained could be possible between the start-up with the same kind of activities. For example, soil indicator results are comparable only between start-ups that directly cultivate lands.

Moreover, between the group of six, start-ups n.6 and n.8 obtained high scores because they declared the cultivation of old varieties of cereals and implemented a net of trees and shrubs in the fields, linking their fields to rural areas nearby, boosting the ES provision. Since no start-up raises animal, related indicators are not present in the analysis.

Overall, using SAFA indicators, the OpenAgri project can be evaluated as a positive sustainability framework for a peri-urban area's requalification. With its grades, the resulting assessment is not a final judgment report. It is an evaluation—and even self-evaluation—tool to have a real-time benchmark to improve or change enterprises strategies. In this view, start-ups should focus their attention on their organisation's peculiar aspects to grow as enterprises. Since all of them have an overall positive impact on the local environment and economy, they should communicate their activities better, implementing certified standards of the already done operations (e.g., ISO UNI norms) to acquire a more structured and aware role in the agri-food market. Further researches may include different evaluation frameworks and tools to underline different aspects and widen sustainability assessments and their correlation with agri-food entrepreneurship projects.

### 4.5 Conclusions

The study shows that entrepreneurship and peri-urban agriculture could foster economic and environmental aspects, bringing sustainable development in neglected areas in our cities' fringe zone—the research analyses a case study located in Milan. The eight agri-food start-ups cultivate peri-urban fields, contributing to forming Local Agrifood Systems (LASs) and improving the socio-economic tissue according to the EU needs, linking local production and its perceived properties (e.g., ecologically sustainable, healthy, traditional, protection of biodiversity) [37]. This research demonstrates the implementation of a LAS and its contribution to the birth of a potential local agri-food start-ups hub, with the effect of developing new job opportunities.

According to the study's objective, eight start-ups' sustainability level verifies their compliance with an international framework. The start-ups' evaluation applying the SAFA framework guarantees adaptability and a holistic approach for assessing sustainability in a different context, e.g., the start-up included associations and enterprises that are very different in terms of internal structure. Indeed, the strong added value of SAFA is the consideration of the four different pillars that compose sustainability—good governance, economic resilience, environmental integrity and social well-being. The framework's application shows that, overall, the start-ups have a high sustainability level, helping to recover a neglected area and respecting the local environment. Moreover, using SAFA results for the start-up could help them show the sustainability of their efforts and activities [50–53] and also recent literature uses SAFA to compare the sustainability of certified and non-certified realities [55]. Therefore, SAFA results show that the involved start-ups should implement a more structured management, with the definition of detailed written internal policies to codify what the start-ups already do in practices. At a higher level, the study demonstrates that peri-urban requalification could link together peri-urban agriculture, social issues and entrepreneurship, resulting in positive environmental, social, and economic aspects in the path to peri-urban sustainability.

**Author Contributions:** Conceptualization, Ambrogio Zanzi, Stefano Bocchi; methodology, Ambrogio Zanzi, Valentina Vaglia, Roberto Spigarolo; software, Ambrogio Zanzi; validation, Stefano Bocchi; investigation, Ambrogio Zanzi, Roberto Spigarolo; data curation, Ambrogio Zanzi; writing—original draft preparation, Ambrogio Zanzi; writing, review and editing, Valentina Vaglia, Stefano Bocchi; supervision, Stefano Bocchi. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding**.**

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgements:** The authors are thankful to OpenAgri project partners for the information and the data provided to conduct the present study. The questionnaire (Appendix A) was developed with dr. Federico Andreotti. The authors acknowledge support from the University of Milan through the APC initiative.

**Conflicts of Interest:** The authors declare no conflict of interest.

**Appendix A**

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**Start-up:** ___________

**(1) What economic value do you aim to obtain from production?**

___________ €/year

**(2) How many people do you think will be employed in your business?**

___1–3 people ___3–6 people ___6–10 people ___more than 10 people

**(3) Do you foresee, in addition to the main crop, other productions or secondary income?**

___ Yes ___No

**If so, what percentage of secondary income compared to primary production?**

__ 0–10% ___10–30% ___30–50%

**(4) How much water do you foresee needing?**

___$m^3$/day

**(5) Have you thought about cultivating species/cultivars with minor water needs?**

___ Yes ___No

**(6) What type of irrigation do you plan to choose?**

___submersion ___sprinkling ___drip irrigatation __subirrigation ___no irrigation

**(7) Do you plan to follow an organic management plan?**

___ Yes ___No

**(8) How deep do you plan to conduct soil tillage:**

___0–15 cm ___15–30 cm __30–50 cm

**(9) Have you thought about choosing species/cultivar less sensible to wind damage?**

___ Yes ___No

**(11) Do you think the presence of hedges and rows as windbreaks is essential for your production?**

___ Yes ___No

**(12) Which species/cultivar will you cultivate?**

| Trees: | Horticultural species: | Forage: | Others: |
|---|---|---|---|
| _______________ | _______________ | _______________ | |
| _______________ | _______________ | _______________ | |
| _______________ | _______________ | _______________ | |

**(13) Do you plan to use agrochemicals? If so, how much will you spend?**

___Yes ___No Budget (€)/year:____€

**(14) Will you adopt biological control techniques? (e.g., pheromone traps, antagonistic insects...)**

___Yes ___No Techniques and budget (€)/year:_____________€

**(15) Which start-ups of the OpenAgri project do you collaborate with? What kind of relationship or exchange do you have?** (e.g., ideas/information; common workforce and equipment; budget and resources...)

| | Start-up 2 | Start-up 3 | Start-up 3 | Start-up 4 |
|---|---|---|---|---|

Start-up 1

| | | | | |
|---|---|---|---|---|
| ____________ | ____________ | ____________ | ____________ | ____________ |
| ____________ | ____________ | ____________ | ____________ | ____________ |
| ____________ | ____________ | ____________ | ____________ | ____________ |
| Start-up 5 | Start-up 6 | Start-up 7 | Start-up 8 | |
| ____________ | ____________ | ____________ | ____________ | |
| ____________ | ____________ | ____________ | ____________ | |
| ____________ | ____________ | ____________ | ____________ | |

**(16) Do you plan to organise education or training activities? If so, what percentage will these activities contribute to the total revenue?**

___ Yes ___No __ 0–10% ___10–30% ___30–50%

Thank you for your time!

**Appendix B**

| Themes | Sub-Themes | Default Indicators | St 1 | St 2 | St 3 | St 4 | St 5 | St 6 | St 7 | St 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| C1 Investment | C1.1 Internal Investment | C1.1.1 Internal Investment | | | | | | | | |
| | C1.3 Long Ranging Investment | C1.3.1 Long Term Profitability | | | | | | | | |
| | C1.4 Profitability | C1.3.2 Business Plan | | | | | | | | |
| | | C1.4.1 Net Income | | | | | | | | |
| C2 Vulnerability | C2.1 Stability of Production | C1.4.2 Cost of Production | | | | | | | | |
| | | C1.4.3 Price Determination | | | | | | | | |
| | | C2.1.2 Product Diversification | | | | | | | | |
| | C2.5 Risk Management | C2.5.1 Risk Management | | | | | | | | |
| C3 Product Quality and Information | C3.1 Food Safety | C3.1.1 Control Measures | | | | | | | | |
| | | C3.1.2 Hazardous Pesticides | | | | | | | | |
| | | C3.1.3 Food contamination | | | | | | | | |
| | C3.2 Food quality | C3.2.1 Food quality | | | | | | | | |
| | C3.3 Product Information | C3.3.1 Product Labelling | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | C3.3.2 Traceability System | | | | | | | | |
| | | C3.3.3 Certified Production | | | | | | | | |
| C4 Local Economy | C4.1 Value Creation | C4.1.1 Regional Workforce | | | | | | | | |
| | | C4.1.2 Fiscal Commitment | | | | | | | | |
| | C4.2 Local Procurement | C4.2.1 Local Procurement | | | | | | | | |

| **Themes** | **Sub-Themes** | **Default Indicators** | **St 1** | **St 2** | **St 3** | **St 4** | **St 5** | **St 6** | **St 7** | **St 8** |
|---|---|---|---|---|---|---|---|---|---|---|
| S1 Decent Livelihood | S1.1 Quality of Life | S1.1.1 Right to Quality of Life | | | | | | | | |
| | | S1.1.2 Wage Level | | | | | | | | |
| | S1.3 Fair Access to Means of Production | S1.3.1 Fair Access to Means of Production | | | | | | | | |
| S2 Fair Trading Practices | S2.1 Responsible Buyers | S2.1.1 Fair Pricing and Transparent Contracts | | | | | | | | |
| | S2.2 Rights of Suppliers | S2.2.1 Rights of Suppliers | | | | | | | | |
| S3 Labour Rights | S3.1 Employment Relations | S3.1.1. Employment Relations | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S3.2 Forced Labour | S3.2.1 Forced Labour | | | | | | | | |
| | S3.3 Child Labour | S3.3.1 Child Labour | | | | | | | | |
| | S3.4 Freedom of Association and Right to Bargaining | S3.4.1 Freedom of Association and Right to Bargaining | | | | | | | | |
| S4 Equity | S4.1 Non Discrimination | S4.1.1 Non Discrimination | | | | | | | | |
| | S4.2 Gender Equality | S4.2.1 Gender Equality | | | | | | | | |
| | S4.3 Support to Vulnerable People | S4.3.1 Support to Vulnerable People | | | | | | | | |
| S5 Human Safety and Health | S5.1 Workplace Safety and Health Provisions | S5.1.1 Safety and Health Trainings | | | | | | | | |
| | | S5.1.2 Safety of Workplace, Operations and Facilities | | | | | | | | |
| | | S5.1.3 Health Coverage and Access to Medical care | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | S5.2 Public Health | S5.2.1 Public Health | | | | | | | | |

| Themes | Sub-Themes | Default Indicators | St 1 | St 2 | St 3 | St 4 | St 5 | St 6 | St 7 | St 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| G1 Corporate Ethics | G1.1 Mission Statement | G1.1.1 Mission Explicitness | | | | | | | | |
| | | G1.1.2 Mission Driven | | | | | | | | |
| | G1.2 Due Diligence | G1.2.1 Due Diligence | | | | | | | | |
| G2 Accountability | G2.1 Holistic Audits | G2.1.1 Holistic Audits | | | | | | | | |
| | G2.2 Responsibility | G2.2.1 Responsibility | | | | | | | | |
| | G2.3 Transparency | G2.3.1 Transparency | | | | | | | | |
| G3 Participation | G3.1 Stakeholder Dialogue | G3.1.2 Stakeholder Engagement | | | | | | | | |
| G5 Holistic Management | G5.2 Full-Cost Accounting | G5.2.1 Full-Cost Accounting | | | | | | | | |

| Themes | Sub-Themes | Default Indicators | St 1 | St 2 | St 3 | St 4 | St 5 | St 6 | St 7 | St 8 |
|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| E1 Atmosphere | E1.1 Greenhouse Gases | E1.1.1 GHG Reduction Target | | | | | | | | |
| | | E1.1.2 GHG Mitigation Practices | | | | | | | | |
| | | E1.1.3 GHG Balance | | | | | | | | |
| | E1.2 Air Quality | E1.2.2 Air Pollution Prevention Practices * | | | | | | | | |
| E2 Water | E2.1 Water Withdrawal | E2.1.2 Water Conservation Practices | | | | | | | | |
| | E2.2 Water Quality | E2.2.2 Water Pollution Prevention Practices * | | | | | | | | |
| E3 Land | E3.1 Soil Quality | E3.1.1 Soil Improvement Practices | | | | | | | | |
| | | E3.1.2 Soil Physical Structure | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | E3.1.3 Soil Chemical Quality | | | | | | | | |
| | | E3.1.4 Soil Biological Quality | | | | | | | | |
| | | E3.1.5 Soil Organic Matter * | | | | | | | | |
| | E3.2 Land Degradation | E3.2.2 Land Conservation and Rehabilitation Practices | | | | | | | | |
| | | E3.2.3 Net Loss/Gain of Productive Land | | | | | | | | |
| E4 Biodiversity | E4.1 Ecosystem Diversity | E4.1.2 Ecosystem Enhancing Practices | | | | | | | | |
| | | E4.1.4 Ecosystem Connectivity * | | | | | | | | |
| | | E4.1.5 Land Use and Land Cover Change | | | | | | | | |
| | E4.2 Species Diversity | E4.2.1 Species Conservation Target | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | E4.2.2 Species Conservation Practices | | | | | | | | |
| | | E4.2.3 Diversity and Abundance of Key Species | | | | | | | | |
| | | E4.2.4 Diversity of Production | | | | | | | | |
| | E4.3 Genetic Diversity | E4.3.1 Wild Genetic Diversity Enhancing Practices | | | | | | | | |
| | | E4.3.2 Agro-biodiversity in-situ Conservation | | | | | | | | |
| | | E4.3.3 Locally Adapted Varieties and Breeds | | | | | | | | |
| | | E4.3.4 Genetic Diversity in Wild Species | | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | E4.3.5 Saving of Seeds and Breeds | | | | | | | | |
| E5 Materials and Energy | E5.2 Energy Use | E5.2.3 Energy Consumption | | | | | | | | |
| | | E5.2.4 Renewable Energy | | | | | | | | |

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# 5. Ecosystem Services assessment in urban environment: a new framework proposal from Milan experience

## Chapter Introduction

This chapter focuses on urban ES assessment and quantification. It deals with a case study located in Milan, where we proposed and applied a new systemic evaluation framework. The chapter presents a copy of the official report delivered to Milan Municipality, without any direct reference to the involved stake-holders.

The need for proposing a new systemic approach comes from the increasing importance and complexity that today urban green infrastructures cover, since they contribute to improve quality of life to urban inhabitants and to reach Agenda 2030 goals, including environmental, social and economic sustainability. Due to this increased importance and to a growing sensibility between public opinion, in the last years, many urban development projects had to take into account the environmental and socio-cultural role of the urban green areas: we should define as "urban regeneration" only those projects able to improve the natural capital in our cities. Today, however, there are no accepted frameworks to assess and evaluate the value of the urban natural capital and the ES provided. Most of the available methodologies are focused on particular components – e.g., soil, trees -, therefore not considering the systemic complexity typical of any ecosystem; moreover, currently available evaluation frameworks offer qualitative and subjective results, with a possible economic value depending on a limited set of indicators, often derived from other scientific branches and adapted to urban ecosystems. Therefore, we propose a new approach, with the characteristic of being systemic, qualitative and quantitative. Systemic since it considers all the natural components – soil, herbaceous layer, shrubs and trees, water cycle, avifauna – and even the human interaction since it analyses the perception of local inhabitants and the relationship with local decision-makers.

Moreover, we managed to conduct a quantitative estimation of the ES provision, not limiting the analysis to a qualitative or subjective perspective. The analysis regards the overall urban natural capital. Urban natural capital considers the stocks of natural assets, including geology, soil, air, water, and all living things (1) that, with citizens, contribute to shape our cities, providing various benefits Ecosystem Services.

The core of these assets is urban vegetation. Urban vegetation – encompassing all trees, shrubs, lawns, and other vegetation in cities –, if adequately managed, can play an important role to ensure a good quality of life and meet the challenges set by Agenda 2030 (2), helping to reach 15 Sustainable Development Goals (3): indeed, in urban environments it can provide several ecosystem services, such as air purification, global climate regulation, temperature regulation, run-off mitigation as well as recreational opportunities, increasing aesthetic values (3). In a few words, urban vegetation can help make cities safer, healthier, wealthier and more attractive, with benefits grouped in social, communal, environmental and economic categories (4). Although this central role, urban vegetation is not often considered a priority by decision-makers, so that budgetary resources are allocated to other areas, perceived as more important. Even worst, most of the time, it is just seen as a cost, even if studies showed that the benefits of urban trees outweigh the costs by ratios of between 1,37 and 3,09 (5), with an estimated value of the provided ES of US $3,8 billion per year in the United States of America (6). Thus, despite years of researches and because urban environment differs from the natural one, urban vegetation lives in inhospitable conditions, so that its lifespan is limited – an urban tree lives on average between 19 to 28 years (7) – impacting their ability to provide long-term services (8). Because of this underestimation, in the last years, many researchers have begun to develop strategies to enhance the impact of nature on human settlements, giving a primary scientific role – yet with many possibilities of growth (3) – to urban nature, its implementation and its management, which is crucial to ensure the optimal contributions to the physiological, sociological and economic well-being of urban societies. Urban vegetation should be studied with an integrated, interdisciplinary, participatory and strategic approach to planning and managing its presence in and around cities (3). Therefore, being an interdisciplinary matter, urban vegetation planning and management is highly complex, having to deal with several topics, such as landscape ecology, arboriculture, urban planning and environmental sciences; meanwhile satisfying the different interests of the stakeholders – mainly, citizens, public authorities, researchers and the involved industries.

Today, the overall urban natural capital needs strong research support for its long-term development, which should address four major components:

i) the conservation, implementation and adaptation of natural entities within cities, in order to improve their fitness to the urban environment, therefore enhancing the provided ES;
ii) the spatial configuration of the urban green areas: well-designed and planned systems can assure better conservation of biodiversity, linking rural and urban areas;
iii) the management of the urban nature – an aspect that still needs to be deeply examined – developing local and tailored plans, thus being able to satisfy peculiar needs;
iv) an improvement in decision-making processes needs to be more participated and transparent with quantitative data provided by reliable frameworks.

The following chapter wants to represent one of the first trials in this direction, a methodology that is still to be fine-tuned and can be replied and implemented in similar case studies.

UNIVERSITÀ DEGLI STUDI DI MILANO

# Urban Ecosystem Service assessment and quantification: a systemic approach and evaluating framework developed in Milan.

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## 5.1 Introduction

The term Ecosystem Services (ES) was introduced in the early 1980s and then developed in the following decade, mainly thanks to the researches of Daily (9) and Costanza (10). The latter conducted one of the first global estimation (10) to calculate the overall value of the ES annually provided by Earth to humanity, with a resulting amount between 16,000 and 54,000 billion dollars. These studies led to further researches developed in limited fields, that were first integrated on an international scale thanks to the *Millennium Ecosystem Assessment* (11). Here, ES are defined as the benefits that humanity obtains, or can obtain, from ecosystems. Costanza proposed 17 types of ES, while MEA reduces them to 4 main categories, strongly underlining the close relationships – with different potentiality and intensity – between ES and human well-being in terms of security, essential material provision, health and social relations – all aspects fundamental to guarantee freedom in choices and actions. MEA analyses ES concept applying the idea of direct use value (to indicate benefits derived from the direct use, whose value can be obtained via surveys), or indirect (to indicate benefits derived from processes, thus not directly available, such as processes that lead to soil formation, water purification, pollination...). Moreover, MEA adds the declination of ES value in different individual and future levels (indicating the value we are willing to assign to the need for conservation and transmission to the next generations of natural resources, therefore not using a part of the available natural resources).

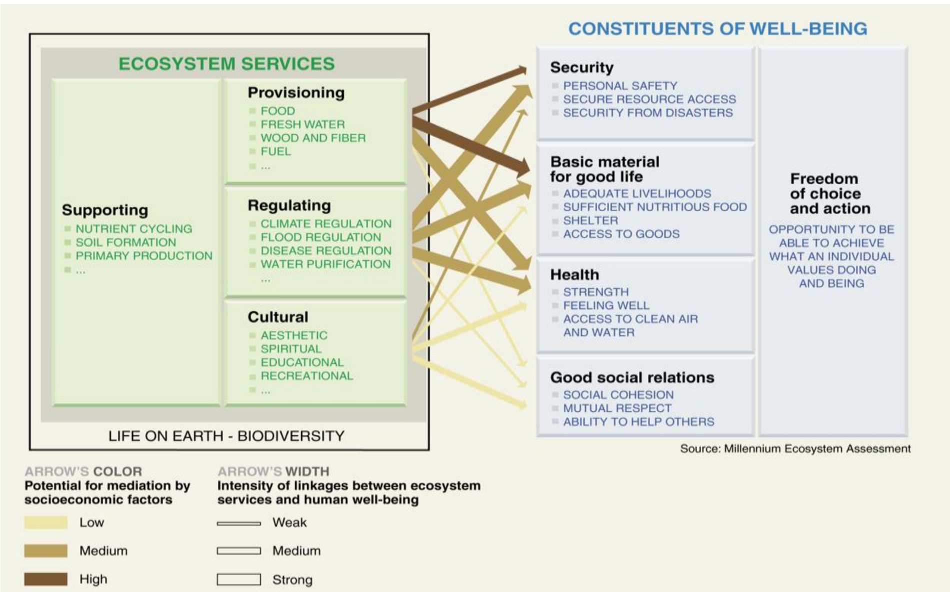

**Fig. 1** Ecosystem services, their classification and relationships with human well-being. Source: Millennium Ecosystem Assessment, 2005.

MEA represents a fundamental milestone: not only it defines the four ES categories, but it raises academic and stake-holders attention on the state of degradation of natural environments, since more than 60% of the ES were classified as at risk (12).

The four categories include provisioning services (e.g., material goods such as food, drinking water, timber, fibres, medicinal plants); regulating services (e.g., environmental processes that have effects on the natural capital as well as anthropogenic activities), and cultural services (e.g., mainly non-material, such as spiritual enrichment, cognitive development, recreational activities, aesthetic values and experiences, knowledge systems, social relationships). To these three main categories, supporting services were added, to indicate fundamental processes – e.g., the production of atmospheric oxygen, the formation and protection of the soil, the water cycle, the formation and maintenance of habitats – necessary to maintain the first three categories.

In the latest years, the ES concept gained even more importance thanks to Agenda 2030 and the achievement of its goals, that underline the importance of providing ES for human well-being: e.g., Agenda's 11 goal highlights the need for sustainability in our city, setting precise targets that should be reached within 2030:

- *11.6 Reduction of the per capita negative environmental impact, paying particular attention to air quality and urban waste management.*
- *11.7 Provision of universal access to safe, inclusive and accessible green public spaces, especially for women, children, the elderly and persons with disabilities.*
- *11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas, strengthening national and regional development planning.*
- *11.b Considerable improvement of cities adopting and implementing integrated policies and plans to foster inclusion, resource efficiency, climate change mitigation and adaptation, disaster resistance, that promote and implement holistic disaster risk management at all levels, following the Sendai for Disaster Risk Reduction 2015-2030.*

Therefore, it is essential to preserve, improve and implement green areas in urban and peri-urban areas, enhancing and evaluating ES provision, to achieve Agenda 2030's ambitious goals, and guarantee sustainable and pleasant environments for citizens inhabitants.

### 5.2 Goals

Starting from these assumptions, during 2020, Università Degli Studi di Milano has been officially involved in a case study to evaluate ES provision in an urban park area in Milan, Italy, where it is ongoing a debated building process with the construction of new buildings and a consequent net loss of green area and permeable soil.

Due to this situation, our research activity aimed at quantifying ES provided before and after the construction project, running simulations to understand the long-term impact – next 30 years – of the construction work on the local environment and ES provision.

The comparison between ES levels before and after the construction works allows us to identify any changes in ecosystem functions and provisions, due to natural capital loss deriving mainly from trees removals and soil sealing and to understand the need for the lost future compensations.

### 5.3 Case Study

Our case study is located in Milan urban area, close to the principal universities and in one of the metropolis' most populated municipality. The area has a total surface of about 20 000 $m^2$, divided into two areas. The first one is currently part of a university structure, and it consists of a mixed presence of buildings and green areas, mainly used by students. Instead, the second area is a typical small urban park, freely available to local inhabitants. Due to the needs for new academic structures, local stakeholders approved a redevelopment plan involving the two areas, which are in spatial continuity.

**Fig. 2** The case study area, as seen in its original land use.

The redevelopment project plans to build new structures in the first area and rethink the public park, trying to ameliorate its aesthetic value. However, this causes a net soil consumption, since most vegetation present in the first area is removed with an increased percentage of soil sealing. Moreover, the decision-making process did not consider public opinion, ignoring local inhabitants' requests of preserving the veteran trees rooted in the first area and the original conformation of the public park.

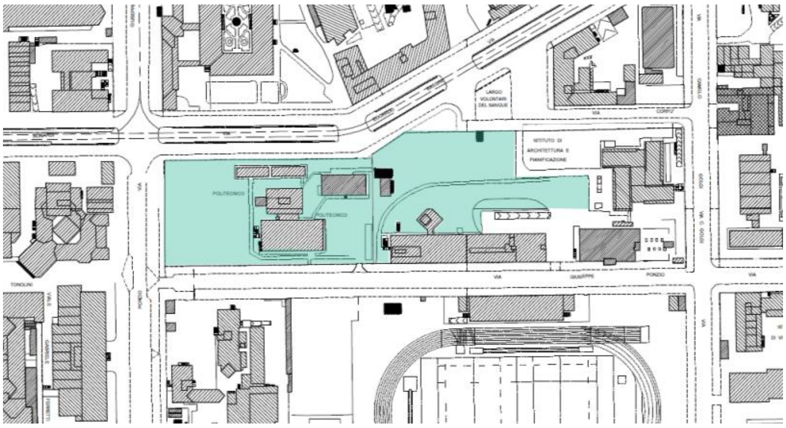

**Fig. 3** Original situation of the case study area.

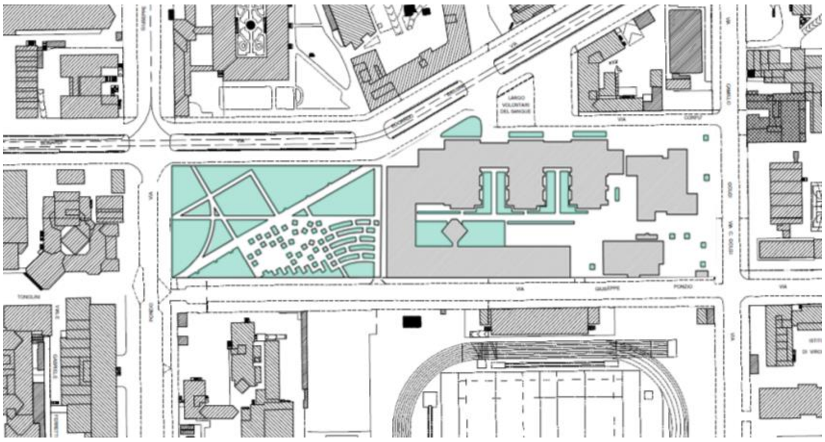

**Fig. 4** Proposal of the redevelopment of the case study area.

This debated situation led to the request of an impartial and quantitative analysis of the overall redevelopment plan, that we carried out to evaluate ES provision in the area, before and after the construction project.

### 5.4 Materials and methods

Our research was developed in different steps:

- Analysis of the available project documentation and development plans;
- On-site surveys, conducted from mid-January to early March 2020 to collect soil and vegetation data;
- Data analysis and processing, thanks to specific software and simulation models, to assess ES provision,
- Analysis of the cultural ES, thanks to a stake-holders investigation via a questionnaire;
- 30-year simulation to understand ES provision at the end of the construction project and in the next future.
- Final quantification of the ES loss, with a quali-quantitative approach.

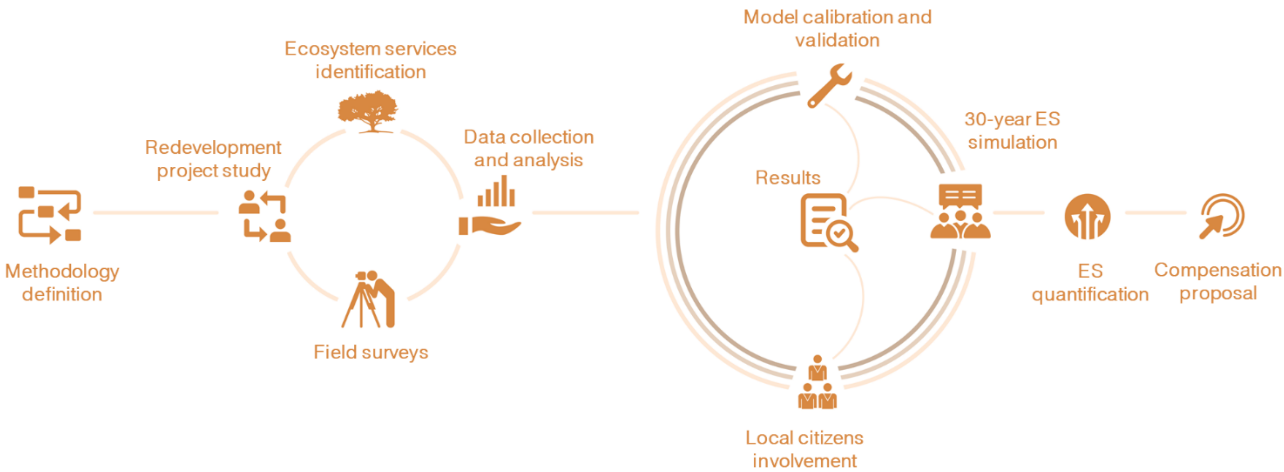


**Fig. 5** Methodological scheme to conduct the ES analysis.

It is important to note that, when our activity began (January 2020), construction activities were already ongoing in the area, causing a significant change in the original environmental conditions, due to partial removal of herbaceous, arboreal, and shrub vegetation, and other works (e.g., preparation to transplant some trees, removal of the original flooring and furnishings) were in progress.

These works had inevitably changed the original state of the area: therefore, our analysis could not be based on a complete field data collection. As shown in fig. 6 and 7, most of the trees and shrubs - which were listed in the available reports as original vegetation – were pruned, cut down or moved between January and February 2020.

**Fig. 6 and 7** The few trees remaining (*Cedrus libani*) heavily pruned, pruning residues in the area. Photos were taken during the site inspection, 29/1/2020.

During our first survey, we noticed that only a few trees (e.g., a couple of *Cedrus libani* and some *Magnolia grandiflora*) were still in place and, in preparation for transplanting, were heavily pruned with numerous cuts, resulting in a harmful topping and an uncontrolled reduction of the crown. This transplanting preparation could only lead to tree death: heavy pruning and incomplete roots preparation in a concise time-lapse result in negative repercussions on tree biology and physiology. This statement was later confirmed by the failure of the transplanting operation, with the trees' felling in Autumn 2020.

Moreover, construction activity caused the eradication of a large part of the herbaceous cover, making the floristic census almost impossible and surely incomplete. Due to these limits, we collected a few samples of trees and shrubs during our surveys, only on the remaining specimens. The soil sampling activity was affected too: it was carried out where conditions allowed it - in the few areas still undisturbed, considered the only representative of the actual soil situation – since most of the soil was hugely hit by the construction work, with a massive passage of heavy vehicles, felling of tree specimens and the uprooting of stumps.

Instead, in the green area not yet subject to construction works and therefore still open to local users, we were able to analyse the original condition: thus, in addition to the soil samples, it was possible to carry out a detailed floristic survey, limited only by seasonality, since winter period is time of vegetative rest for most of the herbaceous species.

In the following months, construction proceeded at full pace, following the project development plans.

Analysing project documents, it clearly emerges that all the greenery in the first area has to be removed – 57 trees to be cut –, as well as a deep renovation should take place in the other green area – at least 40 trees to be cut, with other 23 trees pending future checks – with a compensation proposal only in this area.

Moreover, it emerges that the total area involved in the construction work is equal to 28,996 $m^2$: of these, 15,363 $m^2$ are allocated to existing construction renovating and new buildings construction; 7,321 $m^2$ allocated to park use and 6,312 $m^2$ to roads and paths. Furthermore, the project plans to demolish 3,143 $m^2$ of gross floor area (GFA), which can be defined as the sum of each floor's surfaces composing a building, including external walls, and to build 16,747 $m^2$ GFA, with a net addition of 13,604 $m^2$.

Therefore, analysing the current situation and project plans, it emerges that the net consumption of soil at the expenses of currently green areas (therefore permeable) is approximately of 6,500 $m^2$. Therefore, this surface will be sealed, with a substantial impact on the local natural capital and the ES offered, with a marked increase in water run-off, due to the lower soil permeability.

### 5.4.1 Current decision-making process analysis

In Milan, as in most Italian cities, it is necessary to obtain a specific permission before proceeding at any construction works. Similar restrictions apply if it is necessary to cut trees: the proposer has to present a technical evaluation report to the public offices, following the Milan Municipality rules and requirements. In our case study, the construction project followed the correct process and presented the needed reports, which were accepted. In these reports, a compensation hypothesis is proposed based on the method, currently accepted by the Milan Municipality (13), to estimate the economic value of a tree. According to this method, tree value depends on fixed factors - the definition of which is partly left to the subjectivity of the evaluator - multiplied by a price coefficient, called "unit price", which is a tenth of the price of a tree with ten $cm^2$ of basal area (e.g., having 3.57 cm in diameter or 11 cm in circumference), taken from the 2018 nursery Price List. This methodology considers different tree parameters (aesthetic value, phytosanitary status, size and position) multiplied by the economic value. However, in our case study, this value is very low compared to the actual tree sizes and dimensions: indeed, it is clear that a *Cedrus libani* with a circumference of 11 cm can not be considered equal to a mature specimen with a circumference of more than 200 cm, such as those once found in the area. So, to have a more consistent economic estimate of the original green spaces, it would have been advisable to use bigger plants' prices than those of a nursery price list.

Moreover, with the related economic calculation, the report mainly focuses on tree aspects - such as the aesthetics, position and size of each specimen -, not considering the systemic dimension of the area. Different elements have not been analysed - such as soil and its characteristics; the herbaceous layer; the water cycle; the perception of the green area among citizens and users. All these elements are fundamental to form the natural capital of the area and should be considered during a redevelopment project, since they actively contribute to define the value of the area. This is an evident lack in the evaluation methodology, that leads to a miscalculation of the area's real value: however, the lack is not attributable to planners and architects, but much more the actual methodology required by most Italian cities.

Furthermore, the documents do not show a precise situation of a static and pathological assessment for each tree mentioned in the project tables: it would be useful to have access to this assessment, to better understand the technical and scientific ratio that led to the decision of cutting some trees and to transplant others. Usually, evaluators follow specific protocols – e.g., ISA protocol – to evaluate tree static conditions and then decide the necessary interventions according to a logical process based on four fundamental phases: anamnesis, diagnosis, prognosis and prescriptions. In these protocols, the first fundamental step is to individually evaluate each tree, filling out a VTA (Visual Tree Assessment) form, which reports the tree characteristics and any visible defects, with general information about the environment in which it is rooted. If necessary, the evaluator can deepen the analysis with appropriate tools and techniques (e.g., dendrodensimeter, sonic tomography, pulling tests with SIM method) in order to further investigate the stability of a tree, with the final attribution of a grade (A, B, C, C/D, D), which represents the propension at the failure, establishing re-checks in the following years, or tree care maintenance or removal (grade C/D and D) to be performed immediately (14).

Therefore, both the lack of the current methodology and of the project documents are clearly noticeable. With our work, we tried to have a more complete picture of the natural capital in the area.

### 5.4.2 Herbaceous layer analysis

Our analysis began studying the herbaceous layer. Three field inspections were carried out (in February/March 2020) to complete the herbaceous species' inventory. Most of the species were identified in situ, while few samples were collected to have a sure identification thanks to the discriminating morphological characters and the use of dichotomous keys, according to "Flora d'Italia" (15, 16).

The inventory was then organised in a floristic list, with scientific names (and any synonyms), biological forms and chorotypes derived from Pignatti, bioindication values according to Ellenberg-Pignatti (17), and other particular notations (e.g., allergenicity and toxicity).

With biological form, we mean the strategy adopted by each species to overcome the adverse season, regardless of taxonomic affiliation; chorotype can be defined as the belonging of each species to a geographical distribution area; the Ellenberg/Pignatti bioindication values are a numerical index referring to seven ecological parameters – four regarding soil (pH, organic matter content, water availability, salinity), and three regarding environmental conditions (light, temperature, climate conditions), which represents the optimal environmental conditions of each species for each ecological parameter. Thanks to these indicators, qualitative evaluations of the study area can be derived.

### 5.4.3 Soil and vegetation analysis

At the same time, we investigated soil and vegetation characteristics. During our field visits, soil samplings were taken. At first, eight areas were identified with homogeneous soil characteristics, considering the ongoing construction works. In each area, sub-samples were randomly collected and, according to the quartering method, were then mixed and homogenised, obtaining samples of about 500 g of soil per area (Fig. 8).


**Fig. 8** The eight soil sampling areas.

A certified laboratory then conducted the analyses. The results provided information regarding:

- pH; Granulometry; Total limestone; Active limestone; Organic carbon; Total nitrogen; C/N ratio; Assimilable phosphorus; Exchangeable bases (Na, K, Mg and Ca); Cation Exchange Capacity.

We also looked for the following heavy metal concentrations: Arsenic, Cadmium, Chromium, Mercury, Lead, Copper, Zinc.

It is essential to underline that soil was already modified by construction works, especially in sampling areas 1, 2 and 3 (fig. 8). Therefore, the soil analyses results may not correspond to the original characteristics of the topsoil (first 0-30 cm.) since surface soil had been moved.

Regarding the vegetation, we proceed at collecting samples from the available trees and shrubs (Tab. 1), collecting different parts of each tree:

| **Code** | **Species** | **Leaf** | **Branches** | **Fruit** |
|---|---|---|---|---|
| M1 | *Magnolia grandiflora* L. | 1_A | 1_B | |
| M2 | *Magnolia grandiflora* L. | 2_A | 2_B | |
| M3 | *Magnolia grandiflora* L. | 3_A | 3_B | |
| CD1 | *Cedrus deodara* "Pendula" | 4_A | 4_B | |
| L1 | *Ligustrum ovalifolium* Hassk. | 5_A | 5_B | |
| P1 | *Pyracantha angustifolia* (Franch.) C.K. Schneid | 6_A | 6_B | 6_C |
| B1 | *Lonicera nitida* E.H. Wilson | 7_A | 7_B | |
| C1 | *Thuja* sp. | 8_A | 8_B | |
| CH1 | *Calocedrus decurrens* | 9_A | 9_B | |

| | | | | |
|---|---|---|---|---|
| ND1 | *Nandina domestica* Thunb. | 10_A | 10_B | 10_C |
| La1 | *Laurus nobilis* L. | 11_A | 11_B | |
| Cl1 | *Cedrus atlantica* "Glauca" | 12_A | 12_B | |
| Cl2 | *Cedrus atlantica* "Glauca" | 13_A | 13_B | |

**Tab. 1** List and details of the collected samples.

Corresponding to these site locations:


**Fig. 9** The tree sampling map, 13 samples were performed.

The samples were collected from the remaining specimens still rooted at the time, or, where the construction works were already in place, on the remaining vegetation portions (e.g., stumps and pruning residues on-site). As in soil analysis, we looked for heavy metal concentrations, such as Arsenic, Cadmium, Chromium, Mercury, Lead, Copper, Zinc.

### 5.4.4 ES analysis and quantification

The ES evaluation provided by the green areas was conducted on three different phases:

- firstly, considering the original green areas and natural capital, as it was before the construction works,
- then, assuming and considering as granted the redevelopment plan – thus simulating the ES provision at the end of the works,
- finally, to better understand the natural capital's dynamic evolution, we simulated ES provision in the next 30 years, using as starting point the available construction project.

Regarding the tree and shrub component, which can be seen as an Urban Forest (UF), the I-Tree software (www.itreetools.org), developed by the United States Department of Agriculture (USDA) (18), was used. This software can calculate different benefits provided by trees and shrubs in urban environments; therefore, it was considered the most suitable tool for this kind of study.

The data collected during the inspections were used as input for the model. Since we had no access to the original scenario, our analysis was based both on collected data, both on satellite images, which represents the situation before the start of the work. To understand ES provision granted at the end of the works, we used as input the information provided with the project. Therefore, the first phase took place thanks to the data provided and partly deduced. The second phase was based on data obtained from the project documents to assess the impact of the proposed redevelopment project and the related ES. These data were then subjected to a simulation for the next 30 years, thus considering the greenery's growth and development to have a clearer picture not only in year 0 but in perspective too. Indeed, removing adult and mature trees and shrubs and not being able to replace them with similar elements, it is essential to evaluate the redevelopment project in the medium term, to understand if the newly planted specimens are able to guarantee – or even exceed – the same levels of ecosystem services offered.

The parameters used by I-Tree as input are different and numerous. Given the limited information available, we proceeded to select the few specific or easily calculable inputs, such as weather and pollution data (obtained from Linate airport weather station, the closest to the area), taxonomic information (genus and species), height and diameter of each tree, extension and volume of the canopy and exposure to sunlight. Additional information - crucial for the analysis - such as details of the phytosanitary status have not been entered because not provided and not possible to be estimated. The software, thanks to these inputs, can calculate the following outputs:

- Structure and composition of the urban forest,
- Carbon storage and Carbon sequestration,
- Oxygen production,
- Atmospheric pollutants removal (PM 2,5; $O_3$; $NO_2$; CO),
- Effects on water cycle (avoided run-off).

For each of these outputs, the software – in addition to the quantification – can calculate an economic value, corresponding to the quantities removed multiplied by monetary coefficients (see attachment 1).

Each output is quantified thanks to the use of different mathematical models calibrated and validated for each simulation, with high reliability, certified by multiple peer-reviewed scientific papers, as well as by other case studies concerning urban forests analysis in different parts of the world.

#### 5.4.4.1 Structure and composition of the urban forest

Understanding the actual UF composition is crucial to properly assess and quantify the provided ES. In this perspective, the database has great importance: the more detailed are the data, the greater is the accuracy of the analysis. As explained, the case study is based on a partial data collection, therefore incomplete compared to the vegetation's original structure and composition. Despite this, I-Tree can still analyse UF, providing, for example, a complete framework of the present species, the most common diameter classes and their origin. In addition to these purely informative outputs, I-Tree can calculate leaf area and vegetation cover, used as metadata to quantify ES.

#### 5.4.4.2 Carbon storage and Carbon sequestration

UF role in climate change mitigation is well known, thanks to the capacity of sequestering and storing atmospheric carbon. In particular, trees reduce carbon levels, sequestering it from the atmosphere and storing it in the new growth that develops year after year. To estimate the amount of carbon sequestered, the model bases its analysis on each tree's diameters – provided as input, in the year considered 0 – and then calculates the estimated average annual growth, using specific genus and species parameters and the health conditions provided. Therefore, I-Tree estimates tree diameter and relative sequestration in the year 0 + 1 (19).

Instead, carbon storage can be defined as the amount of carbon in the tree biomass – aerial and underground (20). To calculate C storage, the model estimates each tree's total biomass, starting from the measured data and bibliographic references. Since trees with expanded crown and subjected to maintenance – as the ones under analysis – tend to have less biomass than trees in natural environments, where most of the models are calibrated, I-Tree solve this issue by multiplying the results with a standard coefficient of 0,8. This adjustment is not performed on trees considered as grown in natural conditions. Finally, the model multiplies the dry biomass by 0,5, thus obtaining the carbon stored in each tree.

#### 5.4.4.3 Oxygen production

Oxygen production is one of the main and best-known benefits guaranteed by UF (21). The oxygen produced each year is directly related to the carbon sequestration activity. The total oxygen produced is therefore estimated thanks to C sequestered and its atomic weight:

$$O_2 \text{ produced (kg/year)} = \text{net C sequestered (kg/year)} / 32/12$$

It is interesting to underline that the production of oxygen by vegetation has a relatively minor impact from a global point of view: indeed, our atmosphere contains high and stable oxygen levels, mainly thanks to the aquatic component of the planet.

#### 5.4.4.4 Air pollution removal

Bad air quality is a common issue in many urban areas and can cause various problems to human health and natural ecosystem processes (22). Vegetation, especially in urban environments where anthropogenic pressure is maximum, can lead to air quality improvements, for example, by reducing its temperature, directly removing pollutants and lowering energy consumption in nearby buildings, which consequently reduces emissions of air pollutants due to energy consumption. In our analysis, the model considers vegetation impact on the removal of the most common urban pollutants: ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide and particulate matter (PM) of 2,5 microns.

These estimations on air pollution removal derive from different models (23), which consider the hourly foliar resistances, calculated with a hybrid foliar model. Furthermore, since the removal of carbon monoxide and PM is not directly related to transpiration, the removal rates for these pollutants have been calculated from average values obtained from the literature, adjusted according to phenology and leaf area. Regarding the removal of fine atmospheric particulate, the model considers a resuspension rate equal to 50 % of the deposited particles, which then return into the atmosphere – due to adverse weather, which in particular cases can also lead to an increase in the concentration of PM 2,5 in the atmosphere (24).

#### 5.4.4.5 Future ES simulation provision

To quantify ES provision in the future, it was considered useful to carry out a medium-term simulation – 30 years – to evaluate the evolution and the development of the green area after construction works. This simulation was conducted only on tree and shrub component, implementing the I-Tree Forecast tool (25), not finding in the literature useful and reliable tools to simulate the ES offered by the other components under consideration (soil and herbaceous layer, water cycle and cultural services). This tool simulates UF growth and development in a future period. Providing geographical data, tree information (trunk diameter, obtained from the project), the model can simulate the community's annual evolution, taking into account possible disturbing factors (parasites, adverse weather events) that may alter tree development. Also, the tool allows the setting of some parameters regarding UF vitality, including death rate and new plant/year rate, which affect UF consistency and composition. The tool is thus able to simulate the provision of the following ES:

- Carbon storage
- Carbon sequestration
- Air pollution removal ($NO_2$, $O_3$ and $SO_2$ removed)

As well as for UF composition and evolution.

### 5.4.5 Analysis and quantification of the water cycle

Water cycle management has acquired importance in recent years due to the critical conditions of urban drainage networks and the heavy damage frequently caused by weather events in Milan. To limit these damages, mainly due to uncontrolled soil consumption and soil sealing, Regione Lombardia has adopted a new regional law (n. 7, 23rd November 2017, "Compliance criteria and methodology to respect hydraulic and hydrological invariance") (26) which pursues the principle of hydraulic invariance. This means that, in the case of construction works, the flow and volume rates of meteoric run-off discharged in urbanised areas into natural or artificial receptors must not be greater than those recorded before the construction. This new law aims at avoiding urban floods, with their considerable social, economic and environmental damages. Therefore, in our case study, it appears as a priority to evaluate the water cycle and the surface water run-off in the area. The evaluation is conducted from two points of view: firstly, it is calculated by I-Tree based on UF rainfall interception by tree leaves, in particular simulating the difference between the annual surface run-off with and without vegetation. Although there are different parts of trees (leaves, branches, bark ...) that can play a role in intercepting precipitations and therefore mitigating surface run-off, in the simulation – due to the limited data available and model calibration – it is taken into consideration only the precipitation intercepted by leaves and calculated on each tree's leaf area.

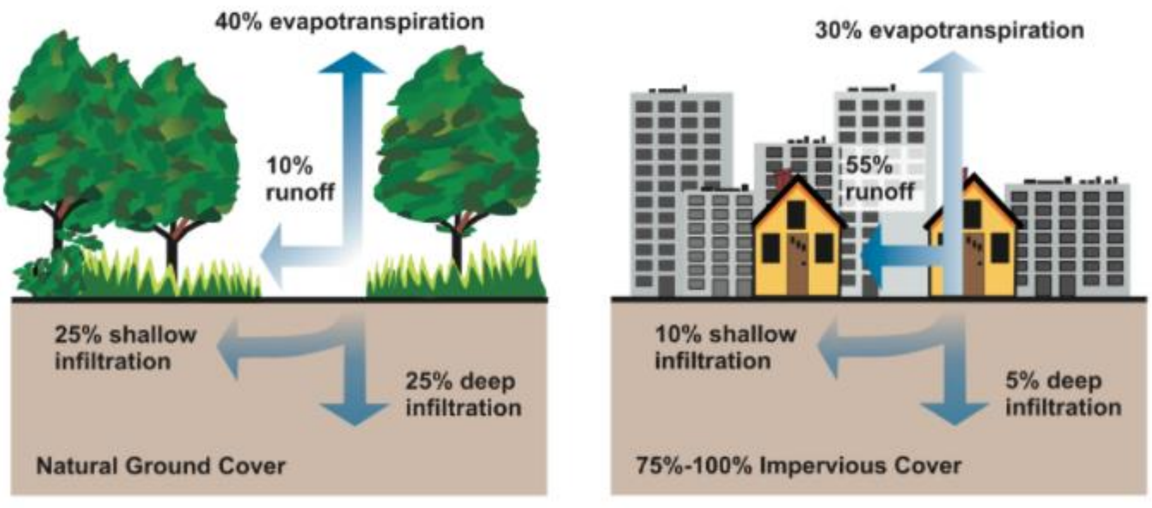


**Fig. 10** Dynamics of water cycle in urban areas, with evident effects due to the different soil sealing percentage. Source: US Dept. of Environmental Protection (2003), Protecting Water Quality from Urban Runoff.

It is then necessary to analyse the water volume capable of reaching the ground despite UF's interception. To analyse and quantify the dynamic of water reaching the ground, it was decided to deepen the analysis using other scientific tools found in literature and to quantify the total run-off volumes, not only those due to tree leaves interception. Indeed, many variables play a fundamental role in the water cycle – and so in surface run-off –, such as soil characteristics, vegetation cover, percentage of sealed soil and slope of the area. Also, we have to consider the overall rain frequency and intensity affecting the area under analysis, and we have to understand which rainy events generate surface run-off. Therefore, to reach a more accurate water cycle assessment, the HIRM-KW model - Hydrological Infiltration Runoff Model - Kinematic Wave) (27) was tested within the case study. HIRM is a hydrological model able to simulate water dynamics (run-off and infiltration) in soils. The model was chosen among several available on the scientific panorama due to its characteristics: its reliability and the strong mathematical background; secondly, because it is a "freeware" software, freely available, with an easy graphic interface. Furthermore, the model was specifically developed to simulate the water infiltration and run-off dynamics in soils characterised by small slopes and limited surfaces, simulating the effects caused by each rain event. Considering the case study characteristics, it was therefore evaluated particularly suitable for our research.

To conduct the analysis, two types of inputs are required: on the one hand, the rainfall recorded on site; on the other, the soil characteristics of the area. Regarding rainfall, we obtained weather data for the 2001-2019 period from the ARPA weather station located in Lambrate, choosing to simulate water cycle dynamics in the year 2019, using sub-hourly weather data (10-minute intervals).

To assess water cycle dynamics, as for the soil sampling activity, the study area was considered divided into the same two areas, considered as homogeneous:

**Fig. 11** The two homogeneous areas where surface run-off was estimated.

This division was made necessary due to the physical obstacles separating the areas, affecting the free water flow. For each of the two areas, HIRM-KW requires different inputs. First of all, topographic parameters (such as width, length and average slope); the Manning coefficient – considered as fixed at 0.3 s/m^1/3 –; and the vegetation cover coefficient, which is considered a constant value 1 $m^2/m^2$. The model requires some physical and hydrological parameters, too, as the Ks – water conductivity at saturation – and $G_0$ – the effective soil net capillarity. To obtain the necessary inputs – in particular bulk density and water conductivity at saturation – we used SoilPar (Soil Parameters Estimate) (28) , a software developed by the Research Centre for Industrial Crops (CRA-CIN), able to calculate soil characteristics, using as inputs texture, topsoil depth and organic carbon, via Jabro and Campbell methods. Thanks to the inputs, HIRM-KW conducts simulations for every single rainy event in the selected time frame, and it can assess the water cycle and quantify surface run-off, which happens when soil infiltration capacity is exceeded. At the end of each simulation, HIRM-KW returns several outputs, including:

- Precipitation hydrogram (total and cumulative);
- Flows depth and rate evolution;
- Infiltration rate evolution;
- Total hydrological balance with the estimation of surface run-off.

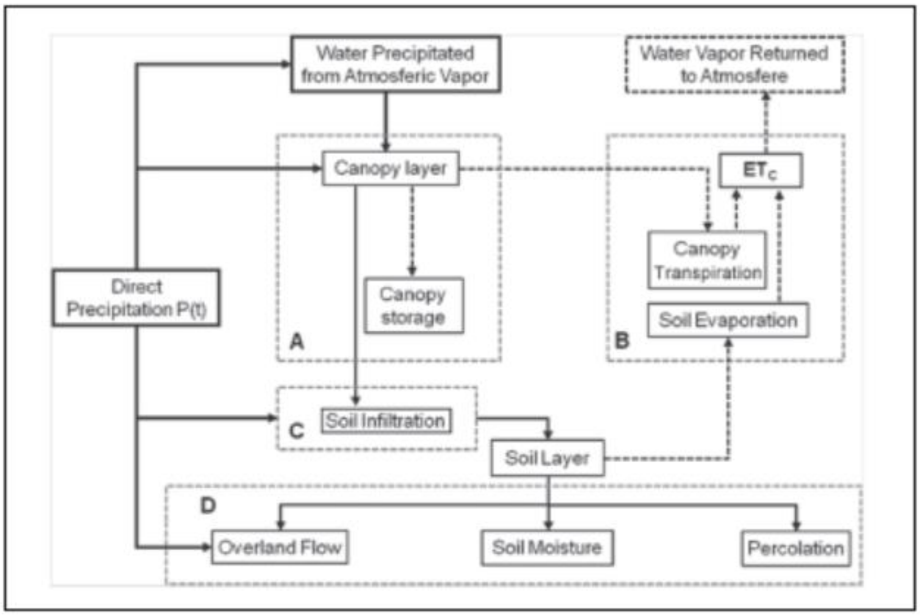


**Fig. 12** Conceptual map of HIRM-KW model with the main hydrological processes considered. Source: Ditto D. et al., 2016, Step by step development of HIRM-KW: a field-scale run-off model, Italian Journal of Agrometeorology.

### 5.4.6 Analysis of the avifauna present in the green area

Green areas represent a precious ecological niche for biodiversity protection in urban contexts. In these environments, the survival of numerous plant and animal species is strictly limited to the presence of natural areas, even of limited size, where they can carry out their vital functions. Therefore, urban green areas represent 'islands' where birds can find shelters, breeding sites and food resources essential for survival. In this context, the birds' census represents a useful tool to encourage policies to protect urban greenery's ecological functions. Moreover, birds provide socio-cultural ES of considerable value in the urban context: firstly, birds observation in urban green areas has an immeasurable aesthetic value. The value of these experiences, such as seeing a robin (*Erithacus rubecula*) outside the kitchen window or listening to a blackbird's melodic song (*Turdus merula*), is difficult to quantify in material and economic terms. However, it is still a valuable emotional and cultural experience. In addition to the aesthetic value, bird presence has undoubted therapeutic value. Some studies (29,30) conducted in urban parks and gardens have highlighted a link between the richness in bird species and benefits for public health in terms of psychophysical well-being and degree of satisfaction in the neighbourhood of residence. Finally, bird presence has an educational and recreational value since their presence intrigues citizens, fosters a passion for nature, and promotes a pleasant and relaxing activity such as birdwatching. The green area under analysis covers all these aspects, and it represents an essential ecosystem for the avifauna that populates the Milanese metropolis. To analyse avifauna composition and richness, surveys were conducted during the year, depending on Covid-19 restriction.

### 5.4.7 Analysis of intangible ecosystem services (cultural ecosystem services)

To complete our analysis, we decided to investigate the so-called cultural ES, which are more difficult to quantify and analyse as they are purely intangible and often depend on subjective aspects. However, it is stated that urban population is becoming everyday more sensible about environmental topics and benefits offered by urban natural capital. To adequately investigate the green area's perception among local citizens, a questionnaire (Attachment 4) was prepared and proposed to the citizens. The questionnaire structure was mainly based on the works of Rosalind (2016) and Collins (2019) (31, 32). In these researches, questionnaires were useful to understand citizenship evaluation of green areas and involve them in developing management policies of public spaces in cities. The same approach was thus applied, looking for information about the green area's perceived value and the overall natural capital. Due to the Covid-19 restriction, the questionnaire was spread via social network and thanks to the local Municipality and universities' collaboration.

### 5.4.8 Validation of the questionnaire

To have reliable results, it is necessary to have a good number of replies and to have a minimum number of valid and completed questionnaires to be considered for the analysis.

To define these numbers, we considered the number of residents around the park, the park user capacity, and the potential number of students using the area since the close classrooms. The first information is obtained using the following proportion and data. The population density in the local Municipality is equal to 9875,19 inhabitants per $km^2$ and the surface area as reported in Milan census classification (source: a dataset of the Geoportal of the Municipality of Milan): 0,07472 $km^2$

$$\mathbf{9875\ inhabitants : 1\ km^2 = X\ inhabitants : 0{,}07472\ km^2}$$

$$\mathbf{X=738\ inhabitants}$$

Therefore, the number of residents close to the park appears to be equal to 738. Of these inhabitants, we estimated that the 5% visited daily the park, corresponding to 37 inhabitants.

$$\mathbf{A=37}$$

The user capacity of the park is derived from the ratio between the permeable surface area of the park and the usable green ratio per capita of 2.3 $m^2$ per inhabitant (source: Municipality of Milan - Milan Green City):

$$\mathbf{12539\ m^2: 2{,}3\ m^2/inhabitant = X}$$

$$\mathbf{X=5451\ person}$$

Of this maximum potential attendance, we considered that the park could be experienced daily by 5 % of these users, equal to 272 users.

$$\mathbf{B=272}$$

The third and final data refers to the number of students who attend close classrooms. Through the available data on classroom capacities, at the moment of students' maximum presence, the classrooms host 1086 students.

Again, we assumed that the 5% of students attend the park to carry out recreational activities. The corresponding value is equal to 54 students.

$$\mathbf{C=54}$$

It must be highlighted that these values are the minimum people who daily visit the site. This was a pure estimation since due to Covid-19 pandemic restrictions, there was no chance to count the park's actual attendance.

We took the resulting average from these data – inhabitants, maximum capacity and users – which is equal to 181.

Therefore, to consider reliable the questionnaire results, at least 181 replies should be collected to assess cultural ES levels.

## 5.5 Results

### 5.5.1 Herbaceous layer results

43 species belonging to 20 families have been registered (see attachment 2). The most represented species belong to *Poaceae* and *Asteraceae* families. One of these families' principal characteristics is to have a typical anemochore dispersion mechanism, not specialised: therefore, they are well suited to colonise anthropized and disturbed environments, such as urban ones. Of the 43 found species, 13 were found only in the disturbed margin areas, while the remaining in lawns.

Biological forms analysis shows that the herbaceous layer is mainly composed of perennial species (percentage that increases in lawn areas), followed by annual species (which are dominant in disturbed margins, as expected: short-cycle species are an excellent anthropogenic disturbance indicator). The presence of Camefite and Geophytes species is limited.

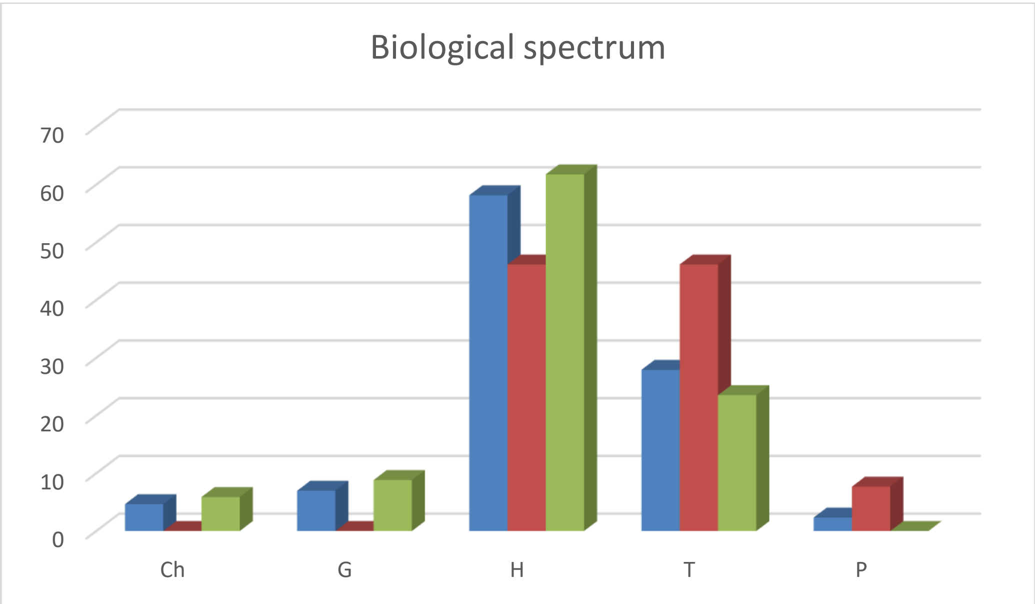


**Fig. 13** Biological spectrum of the herbaceous species surveyed. Blue bar: overall spectrum; red bar: marginal areas; green bar: lawn area.

From a chorological point of view, the area - especially in the marginal spots - is dominated by Cosmopolitan species, as typical in anthropized areas, with a good presence of European-Asian species, in line with the territorial biogeographical context. The presence of exotic species (especially invasive) is marked.

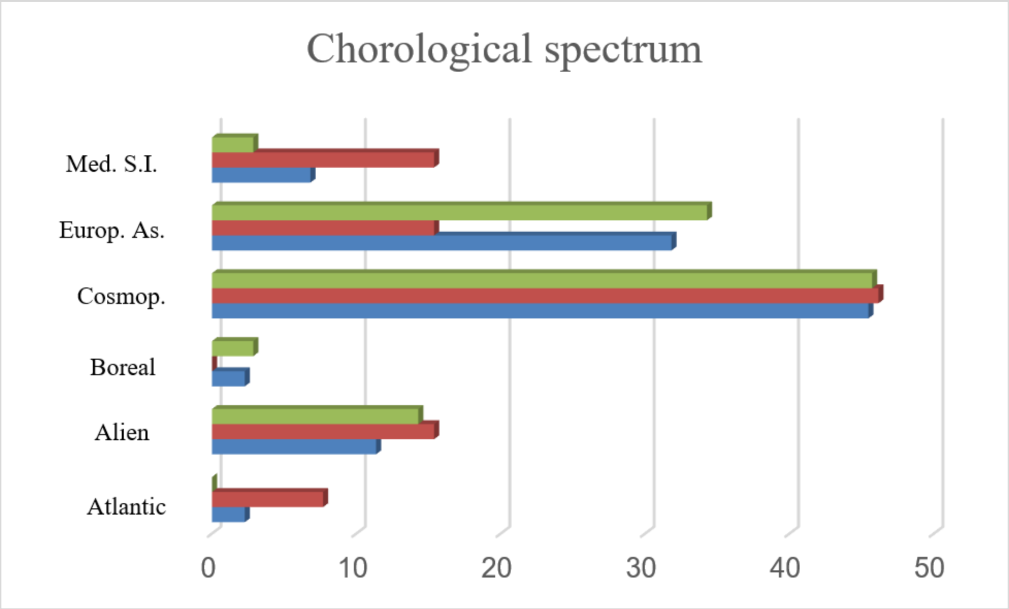


**Fig. 14** Chorological spectrum of the area, from which Cosmopolitan species' predominance emerges, own elaboration. Blue bar: overall spectrum; red bar: marginal areas; green bar: lawn area.

The Echogram of the overall herbaceous presence – which is the graphic expression of the Ellenberg/Pignatti bioindication values – shows average conditions in light exposure (a bit higher in lawn areas) and temperature, typical of a continental climate. Simultaneously, according to the bioindicators, the soil is characterised by limited water availability, the average content of organic matter and neutral-acid reaction.

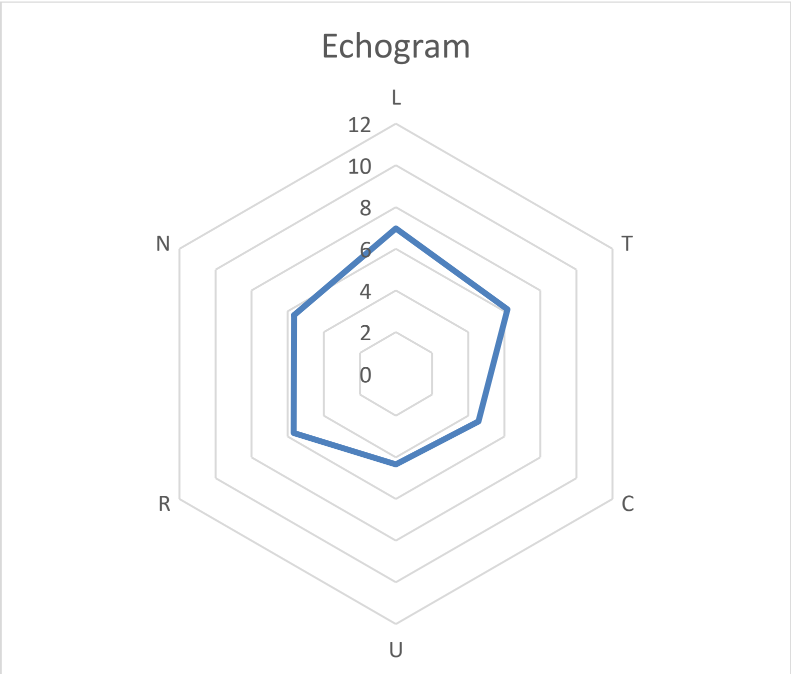


**Fig. 15** Echogram of the area under analysis, own elaboration.

No spontaneous shrub and tree species were found in lawns and margins, where we focused our census of herbaceous species. Considering the herbaceous layer, we can affirm that the area is relatively poor in specific biodiversity, with a limited qualitative value of the present species, since they are common in urban environments, with a non-specialised dispersal mechanism. Again, we have to highlight that in the area where the construction site is located, the works have compromised the herbaceous cover; whereas, in the park area, herbaceous cover suffers from two limits: on the one hand, tree's shade avoids a proper light presence; on the other, the soil is compacted due to human presence and activity. These factors do not favour the presence of herbaceous species since environmental conditions are not optimal to grow and develop properly.

The current state of the herbaceous layer certainly provides socio-cultural ES. However, ES provision could be implemented and improved since few regulating services are offered due to environmental limits – soil too compacted, few pollinations since most of the species are anemophily and do not reach flowering, low photosynthetic efficiency and poor absorption and sequestration of $CO_2$ – that cause a discontinuous herbaceous cover. Finally, the presence of exotic species does not contribute to an increase in biodiversity levels since these species are colonising the area at other species' expense.

### 5.5.2 Soil and vegetation analysis results

Interesting results emerge from the soil analyses. Figure 16 summarises the characteristics of the soil texture where the samplings were collected. Same figure highlights where tree sample was collected.

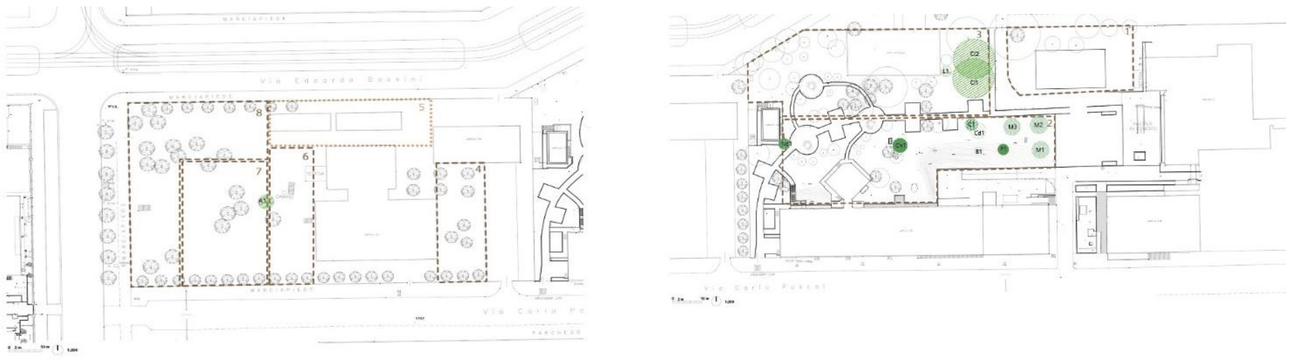

**Fig. 16** Soil texture **-** divided by sampling areas **-** and the plant samples' location collected and analysed.

The following figures show the results of the analysis of the main soil parameters.

PH, which can be defined as a scale to measure the acidity or basicity of a solution, regulates the solubility and availability of nutritional elements, thus acting on plant growth and development. The analysed soil samples show that, in the area, pH values are close to neutrality, with a slight tendency to alkalinity in three areas, which does not affect soil quality.

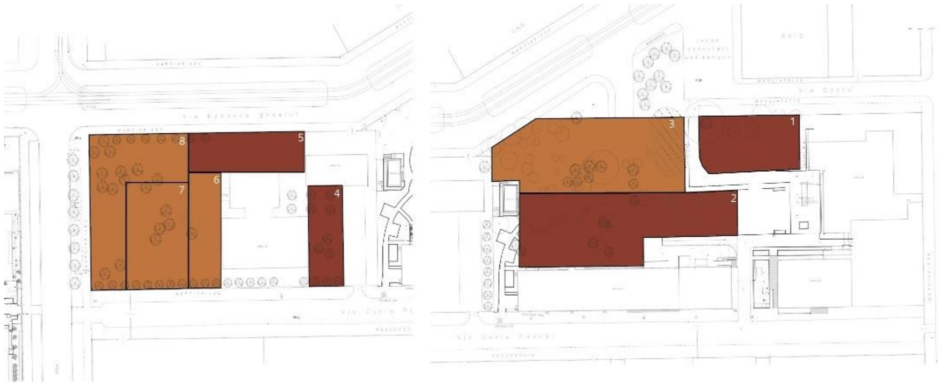

**Fig. 17** pH values measured area by area. Light brown areas: neutral values (6,7-7,2); dark brown areas: subalkaline values (7,3-8).

The C/N ratio is a ratio between Carbon and Nitrogen concentration in soils. This ratio changes by adding carbon to the soil – e.g., distributing organic matter –, causing possible issues to the soil microorganism. These microorganisms degrade plant residues using nitrogen in the soil, thus consuming it. C/N ratio is thus a widely used index to assess the availability of nitrogen in the soil. From the analyses, a contrasting situation emerges indeed, while in the green areas still open to the public, the C/N values are optimal; in the construction site, the values are defined as low, probably due to the work in progress.

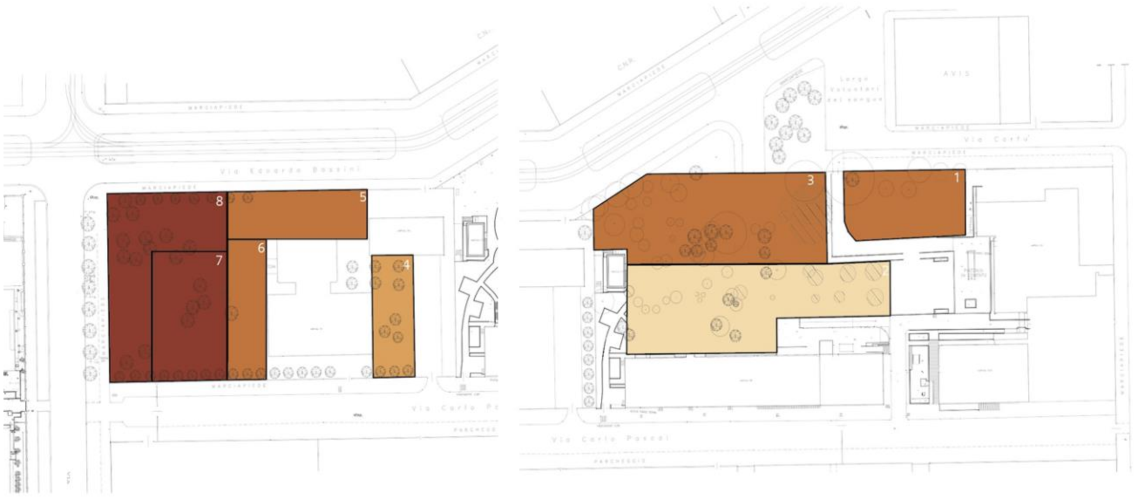

**Fig. 18** C/N report and relative agronomic judgment. Light brown areas: low values (3-5); dark brown areas: high values (>12).

The last analysed parameter is the organic matter, which plays a fundamental role in soils, improving its structure, promoting microorganisms proliferation and decreasing leaching. Usually, in agricultural soils, a percentage concentration of 2-3% is considered as good. In urban soils, the evaluation should be different, since there are no productive purposes, but purely ornamental, and the removal of arboreal and herbaceous specimens is close to zero, as well as minimal is soil tillage: these factors contribute to maintaining good levels of organic matter – and this emerges from our analyses.

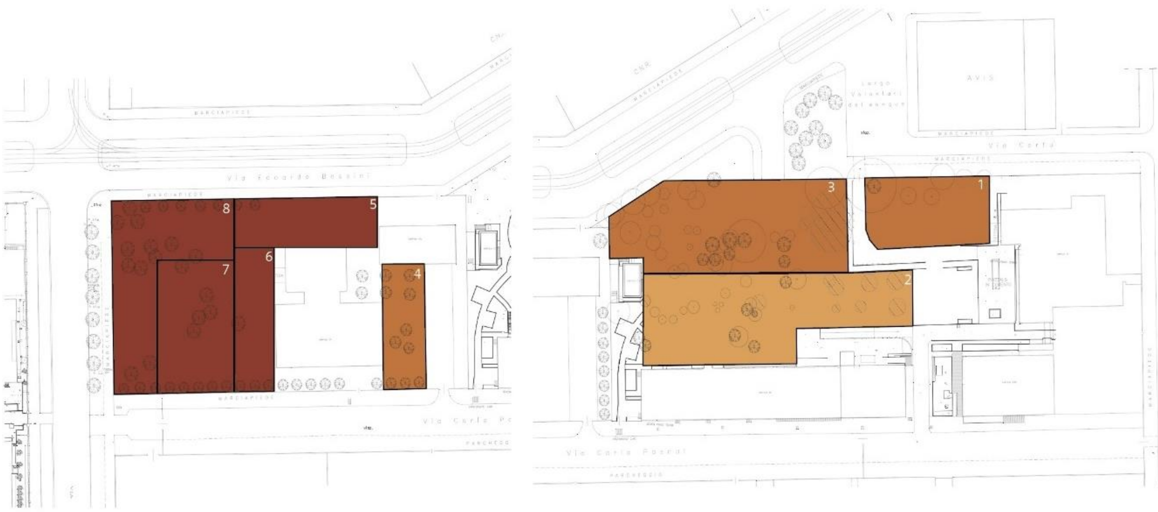

**Fig. 19** Percentage values of organic matter detected area by area and relative agronomic judgment. Light brown areas: low values (0,8%-1,2%); dark brown areas: high values (2%-4%).

In addition to chemical parameters, heavy metals concentration was analysed. To evaluate the results and to understand if the found values are critical, we took as a benchmark the national legislation (D. L. 152/2006). In particular, within the law, the third part ("Regulations on soil protection and desertification control, protection of water from pollution and management of water resources") fixes the admitted concentration level of each heavy metal. Table 1, Annex 5, Title V shows the admitted threshold concentrations in soils, referred to as different land uses, public green use (part a), private and residential and commercial and industrial use (part b) (table 2).

Our analysis emerges that in some collected samples (Table 3), the concentration values exceed the legal limits.

| **Concentration levels (Table 1, Annex 5, DL 152/06)** | | |
|---|---|---|
| | **Land use A** | **Land use B** |
| **Metal** | **Land use: public green area (mg/kg)** | **Land use: private and residential and commercial and industrial use (mg/kg)** |
| **Antimony** | 10 | 30 |
| **Arsenic** | 20 | 50 |
| **Beryllium** | 2 | 10 |
| **Cadmium** | 2 | 15 |
| **Cobalt** | 20 | 250 |
| **Total Chromium** | 150 | 800 |
| **Chromium VI** | 2 | 15 |
| **Mercury** | 1 | 5 |
| **Nickel** | 120 | 500 |
| **Lead** | 100 | 1000 |
| **Copper** | 120 | 600 |
| **Selenium** | 3 | 15 |

**Tab. 2** Heavy metal threshold concentrations in soils referred to different uses. From: Legislative Decree 152/2006, table 1, Annex 5, Title V.

| **Sample** | **Copper** | **Zinc** | **Lead** |
|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 3 | Above the threshold for both land uses | | | |
| 4 | | | | Above the threshold for land use A |
| 5 | | | Above the threshold for land use A | Above the threshold for land use A |
| 6 | | | Above the threshold for land use A | Above the threshold for land use A |
| 8 | | | Above the threshold for land use A | |

**Tab. 3** Soil samples in which the concentration values exceed admitted thresholds as indicated by current regulations (Tab. 2).

Therefore, it emerges that, in some sampled points, there are values above the allowed thresholds for three heavy metals: lead, copper and zinc. This situation is quite common in an urban environment. Urban and peri-urban soils are subjected to various stresses, especially in past decades – e.g., atmospheric pollution, pollutants coming from cars, anthropogenic interference, and construction works –, which can lead to an accumulation over the years. This causes a remediation problem, although heavy metals' impact is considered limited as the intended use is not productive, and therefore there is no risk of contamination through the food chain.

Regarding tree samples, in the analysed tissues (leaves and branches), copper, zinc, and cadmium were found, absorbed and accumulated in the tissues (Tab. 4).

| ID_analysis | ID_sample | Species | As (mg/kg) | Cd (mg/kg) | Cr (mg/kg) | Hg (mg/kg) | Pb (mg/kg) | Cu (mg/kg) | Zn (mg/kg) |
|---|---|---|---|---|---|---|---|---|---|
| 1a | M1 | *Magnolia grandiflora* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4,8 | 15,1 |
| 1b | M1 | *Magnolia grandiflora* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4,7 | 7,3 |
| 2a | M2 | *Magnolia grandiflora* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4,3 | 12,9 |
| 2b | M2 | *Magnolia grandiflora* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 6,4 | 12,5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 3a | M3 | *Magnolia grandiflora* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4,2 | 11 |
| 3b | M3 | *Magnolia grandiflora* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | < 2,5 | 5,1 |
| 4a | CD1 | *Cedrus deodara* "pendula" | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | < 2,5 | 11,7 |
| 4b | CD1 | *Cedrus deodara* "pendula" | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 3,8 | 18,9 |
| 5a | L1 | *Ligustrum ovalifolium* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 8,4 | 88 |
| 5b | L1 | *Ligustrum ovalifolium* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 11,8 | 70 |
| 6a | P1 | *Pyracantha angustifolia* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 3,7 | 31 |
| 6b | P1 | *Pyracantha angustifolia* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 5,4 | 16,4 |
| 6c | P1 | *Pyracantha angustifolia* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 2,5 | 4.8 |
| 7a | B1 | *Lonicera nitida* | < 2,5 | 0,55 | < 2,5 | < 5 | < 2,5 | 7,7 | 29 |
| 7b | B1 | *Lonicera nitida* | < 2,5 | 0,5 | < 2,5 | < 5 | < 2,5 | 8,3 | 26 |
| 8a | C1 | *Thuja* spp. | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 2,6 | 14,2 |
| 8b | C1 | *Thuja* spp. | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4 | 16,7 |
| 9a | CH1 | *Calocedrus decurrens* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 3,5 | 7,9 |
| 9b | CH1 | *Calocedrus decurrens* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 2,5 | 8 |
| 10a | ND1 | *Nandina domestica* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4,1 | 21,9 |
| 10b | ND1 | *Nandina domestica* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 6 | 23,8 |
| 10c | ND1 | *Nandina domestica* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 6,6 | 10,7 |
| 11a | LA1 | *Laurus nobilis* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 5,6 | 10,4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 11b | LA1 | *Laurus nobilis* | < 2,5 | 1,1 | < 2,5 | < 5 | < 2,5 | 4,3 | 49 |
| 12a | Cl1 | *Cedrus atlantica* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | 4,4 | 15,3 |
| 12b | Cl1 | *Cedrus atlantica* | < 2,5 | < 0,5 | < 2,5 | < 5 | 6,5 | 19,8 | 50 |
| 13a | Cl2 | *Cedrus atlantica* | < 2,5 | < 0,5 | < 2,5 | < 5 | < 2,5 | < 2,5 | 5,5 |
| 13b | Cl2 | *Cedrus atlantica* | < 2,5 | < 0,5 | < 2,5 | < 5 | 2,7 | 10,3 | 28 |

**Tab. 4** Trees and shrubs samples with heavy metal concentrations.

In light of these results, any possible hypothesis that considers the redevelopment of the area for productive purposes (e.g., the creation of urban gardens) is to be excluded.

#### 5.5.3 Pre-construction ES assessment of green areas

Regarding the ES provided by trees and shrubs, the results can be divided into two parts: a first one referring to the actual situation and a second one that analyses the project proposal to understand the ES provision level. Regarding the first phase, the following results were obtained applying I-Tree Eco software's models:

##### 5.5.3.1 Structure and composition of the UF

Overall, the green area under analysis consisted of 6,615 $m^2$ in tree cover and 2,95 hectares of leaf area. The most common species were *Populus nigra*, *Platanus x acerifolia* and *Tilia x europaea*. Most trees had small/medium-sized classes of diameter at breast height (DBH) - most between 45,7 and 61 cm. interval. This means that the tree population was mainly composed of relatively young trees, certainly not at the end of their cycle.

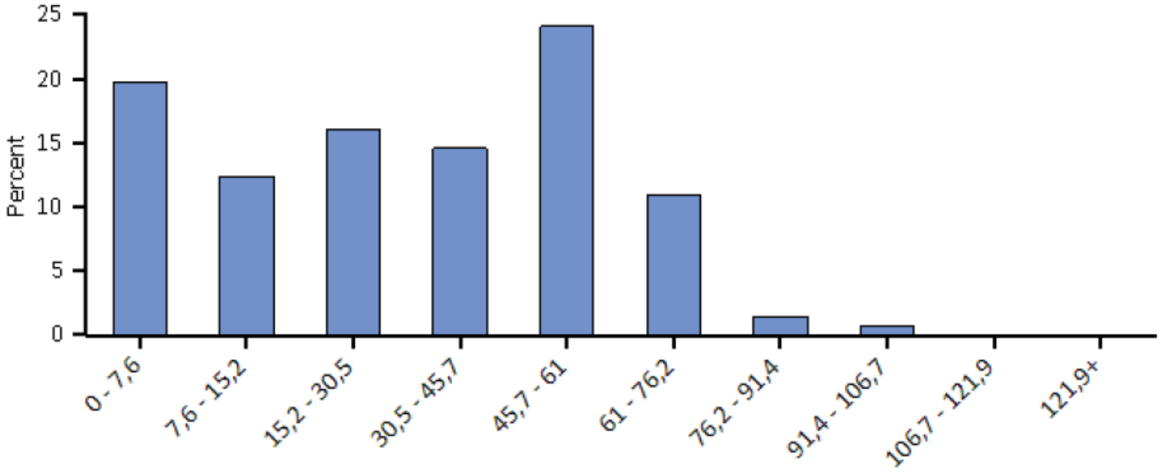


**Fig. 20** Classes of diameter at breast height (conventionally fixed at 1,37 m. from ground level) of the tree populations.

#### 5.5.3.2 Air pollution removal

Trees and shrubs remove 30,93 kg of pollutants per year in the area every year. In particular, ozone is the most captured and removed one:

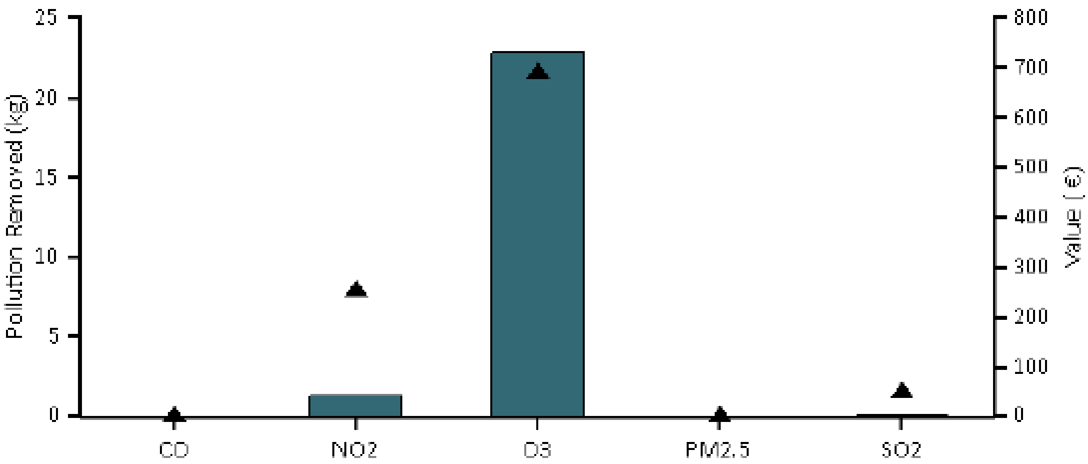


**Fig. 21** Pollutants removed. The bars indicate the quantities, the points the corresponding economic value.

#### 5.5.3.3 Carbon storage and sequestration

The UF community sequesters 1507 kg of carbon per year, considering the annual growth. The carbon stored instead is equal to 66,4 tons. In particular, *Populus nigra* var. Italica store and sequester most of the carbon – 55.4% and 49%, respectively.

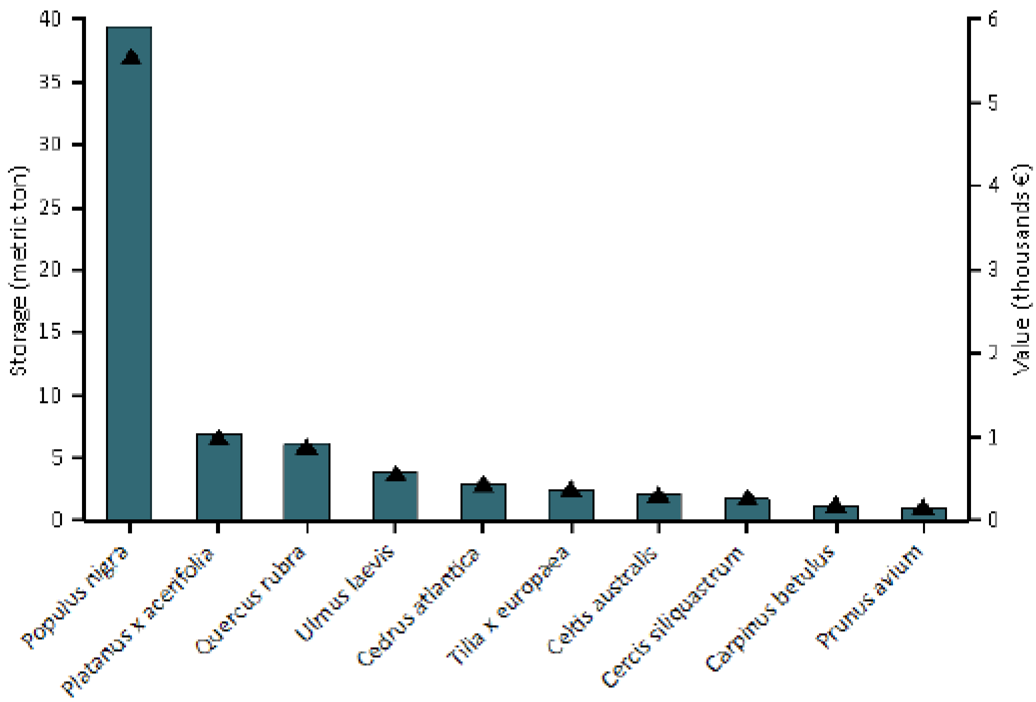


**Fig. 22** Estimated carbon storage – points – and associated value – bars – in the case study.

#### 5.5.3.4 Oxygen production

The UF produces 4,019 tons of oxygen per year. In particular, the most contributing species are *Populus nigra* var. Italica and *Quercus rubra*.

| Species | $O_2$ production (kg/yr.) | C sequestration (kg/yr.) | Number of trees | Leaf area (ha) |
|---|---|---|---|---|
| *Populus nigra* | 1.971,04 | 739,14 | 38 | 1,12 |
| *Quercus rubra* | 367,71 | 137,89 | 9 | 0,23 |
| *Platanus x acerifolia* | 315,64 | 118,37 | 5 | 0,34 |
| *Ulmus laevis* | 219,78 | 82,42 | 6 | 0,23 |
| *Tilia x europaea* | 197,3 | 73,99 | 20 | 0,25 |
| *Celtis australis* | 142,53 | 53,45 | 4 | 0,17 |
| *Cedrus atlantica* | 129,19 | 48,45 | 5 | 0,11 |
| *Cercis siliquastrum* | 113,81 | 42,68 | 3 | 0,07 |
| *Magnolia grandiflora* | 82,41 | 30,9 | 3 | 0,05 |
| *Fagus sylvatica* | 79,84 | 29,94 | 3 | 0,09 |
| *Carpinus betulus* | 79,29 | 29,73 | 11 | 0,06 |
| *Prunus avium* | 60,83 | 22,81 | 1 | 0,03 |
| *Prunus pissardii* | 39,66 | 14,87 | 7 | 0,03 |
| *Magnolia x soulangeana* | 39,52 | 14,82 | 4 | 0,03 |
| *Robinia pseudoacacia* | 35,62 | 13,36 | 3 | 0,03 |
| *Acer platanoides* | 29,03 | 10,89 | 2 | 0,03 |
| *Betula pubescens* | 25,57 | 9,59 | 1 | 0,02 |
| *Ailanthus altissima* | 21 | 7,88 | 1 | 0,02 |
| *Mespilus germanica* | 15,89 | 5,96 | 1 | 0,01 |
| *Eriobotrya japonica* | 15,59 | 5,85 | 1 | 0,01 |

**Tab. 5** List of species and contribution to oxygen production.

### 5.5.4 Water cycle analysis and surface run-off quantification

As explained, the water cycle was considered on two different levels. Water follows different paths – in part, it evaporates, in part, it infiltrates the soil, and in part it flows on the surface, generating surface run-off. However, a first share is intercepted by trees and shrubs. This first share was estimated thanks to I-Tree's implementation and was found equal to be 83.9 $m^3$. The remaining part of water reached the ground, and thanks to HIRM-KW, we simulated its path. This model, as explained, works on daily base with a sub-hourly time interval. To have aggregated annual data, we proceeded to simulate each rain event, then summing the results to obtain the total annual surface run-off. The simulation regarded the year 2019, and it was conducted dividing the total area into two lots, as explained. We obtained the following results:

| Area | Overall surface ($m^2$) | Sealed soil | Rainfall water ($m^3$) | Surface run-off ($m^3$) |
|---|---|---|---|---|
| **Construction site** | 14660 | 54% | 16574 | 10936 |

| | | | | |
|---|---|---|---|---|
| **Park area** | 7973 | 28% | 9014 | 5030,9 |

**Tab. 6** Cubic meters of the water precipitated in the two lots and its dynamics.

These values can be taken as a benchmark for the redevelopment project so that the construction does not cause an improvement of water run-off due to an increase in soil sealing.

### 5.5.5 Avifauna analysis

Our activity consisted of preliminary monitoring, and it highlighted a significant presence of bird species: some widespread, such as blackbirds (*Turdus merula*) and pigeons (*Columba livia*); others less known to citizens, such as the *Parus major*. The monitoring was conducted in a non-ideal period of the year: this activity should be carried out during the birds' breeding season, which is in spring. Unfortunately, the Covid-19 restriction has precluded to complete this activity, which will be defined in spring 2021.

### 5.5.6 ES provision simulation in 30-years

We then evaluated ES provision in 30 years, using the construction project database as model input. This evaluation aims to compare the future ES offer with what the park once provided prior the construction works.

- **Carbon storage and sequestration**

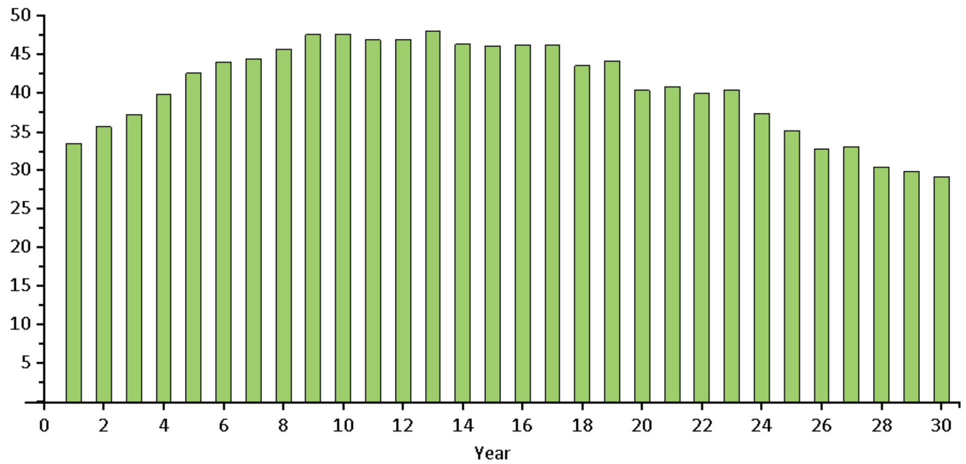


**Fig. 23** Carbon sequestration in the next 30 years.

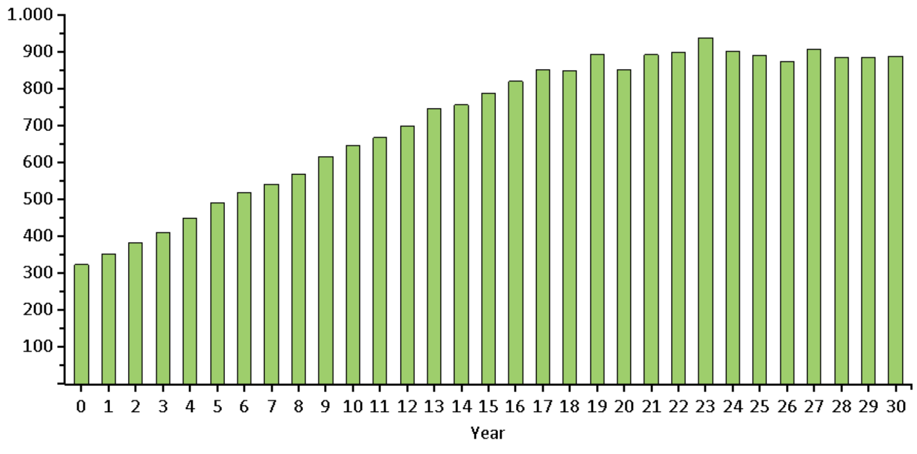


**Fig. 24** Carbon storage in the next 30 years.

- **Air pollution removal**

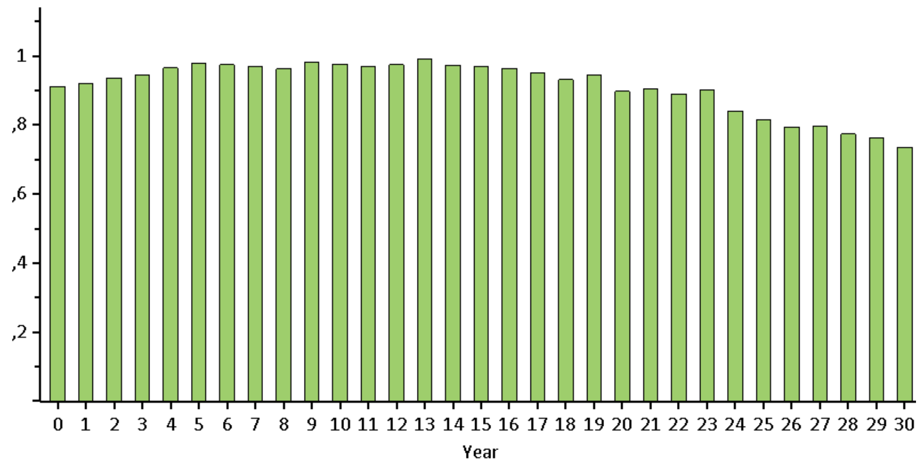


**Fig. 25** Removed $SO_2$ in the next 30 years.

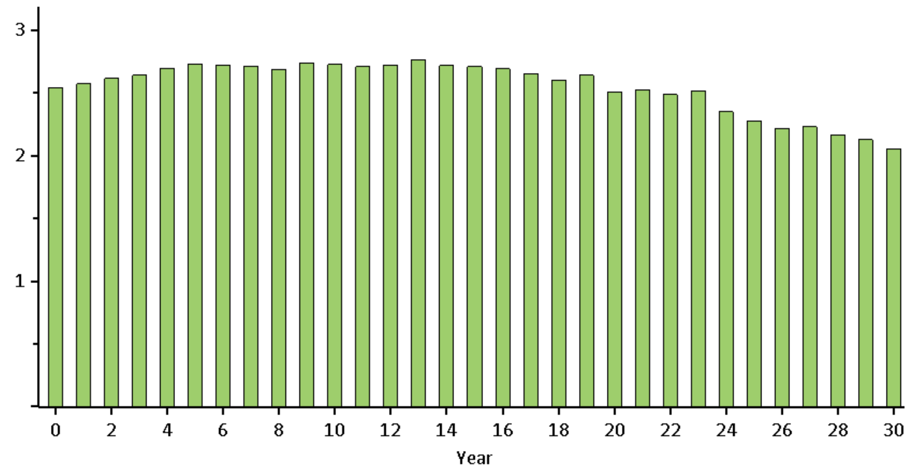


**Fig. 26** Removed $O_3$ in the next 30 years.

- **Future effects on the water cycle**

Simulating construction project's effects on water cycle is not easy since the analysis has to be based on annual precipitation data and their intensity on a sub-hourly base, which can not be foreseen. Therefore, it was decided to proceed by hypothesis, basing our estimation on a fixed point – soil sealing increase – and evaluating precipitation trend forecast provided by the European platform Copernicus-Climate Change Service (https://edudemo.climate.copernicus.eu/). This platform considers the European rainfall since 1971 and, through models based on Copernicus satellite surveys (33), can simulate rainfall up to year 2100 on a national and regional scale. In Northern Italy, a slight decline in the total amount of precipitation is expected (1,152.6 mm/year in 2050, 1,019.66 mm/year in 2100). However, the intensity of rainy events, an essential factor in assessing surface water run-off, can not be estimated. Assuming rain volumes similar to the actual ones and considering the increase in sealed surface (increase of 6,500 $m^2$) in the construction area, once the project will be completed, there will certainly be an increase in run-off, since a bigger quantity of water will no longer be able to infiltrate the soil. The impermeable soil will be increased by 36 % compared to the pre-construction situation (from 54 % to 90 %), with a possible consequent proportional increase in surface run-off.

### 5.5.7 Regulating ES consideration

Therefore, it is evident that the ES provided by the redevelopment project, even in the medium term, is not sufficient to reach the pre-existing ES levels. This is essentially due to a few reasons:

- net soil consumption, with a reduction of permeable soil available to greenery;
- planting of trees and shrubs of limited size, compared to what once rooted;
- predominance of shrub species over trees, with a more limited ES contribution, especially regarding regulation services.

| | Regulating ES - Trees and shrubs component | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Original condition (pre-construction) | | | | | | Construction project implementation | | | | | |
| | Tree cover | C storage | C sequestration | Air pollution removal | Oxygen prodution | Avoided run-off | Tree cover | C storage | C sequestration | Air pollution removal | Oxygen prodution | Avoided run-off |
| Year 0 | 6615 m2 | 66,4 ton | 1507 kg/year | 30,93 kg/year | 4,019 t/year | 83,9 m3/year | 3162 m2 | 13,12 ton | 409,2 kg/year | 13,22 kg/year | 1,091 t/year | 32,04 m3/year |
| Year 30 | | | | | | | 3735 m2 | 8,94 ton | 307 kg/year | 14,2 kg/year | | |

**Fig. 27** Quantitative comparison between pre-construction scenario, year 0 and year 30 redevelopment project

### 5.5.8 Analysis of intangible ecosystem services (cultural ecosystem services)

170 people replied to the questionnaire. Of these, 138 replies were complete in each question, and only these were considered valid and analysed. Even if under the fixed threshold, the obtained answers let us understand the critical role of the park for daily users. Useful and interesting information emerged from the replies.

First of all, the provenience of those who answered the questionnaire: almost 50% of the answers came from inhabitants of the local Municipality – which includes the case study area – followed by nearby municipalities.

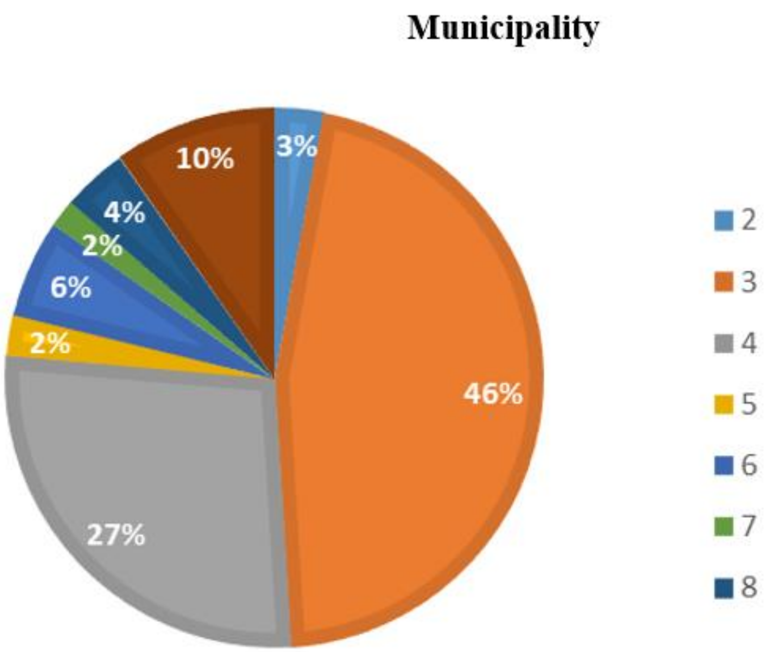


**Fig. 28** Area of residence of the users who answered the questionnaire.

Furthermore, it emerges that only 13% of replies arrived from people under 25-year-old people – which are identifiable with university students: the low participation of young people may be due to a misperception of this particular case study since they do use and enjoy the area, but the majority do not live nearby, and therefore they do not perceive the problem as the inhabitants.

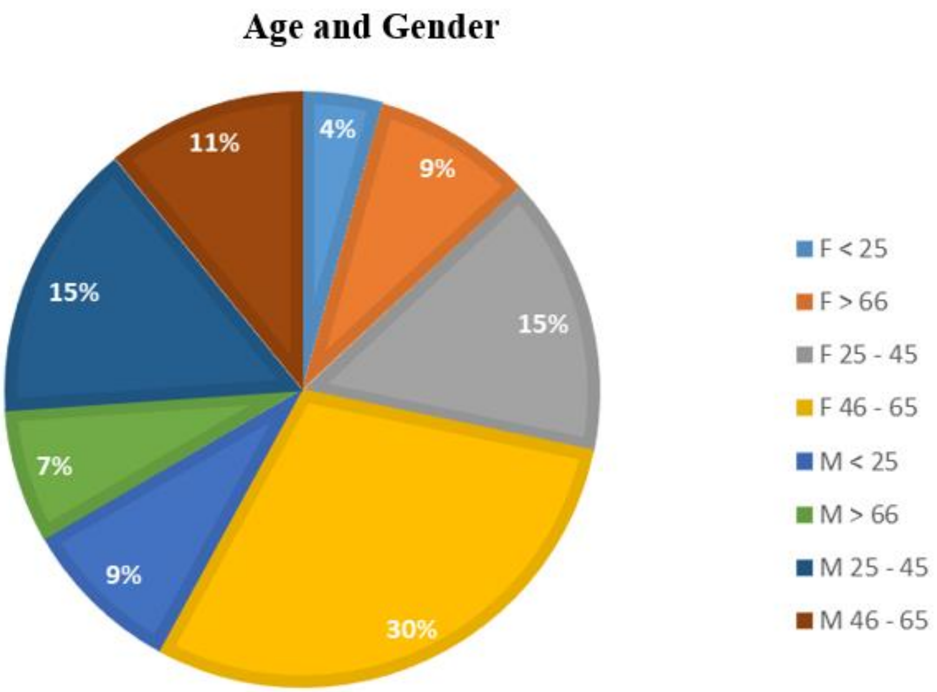


**Fig. 29** Age ranges of users who answered the questionnaire.

Anyhow, among the answerers, we noticed a high familiarity with the topics and ES concepts: over 60 % affirmed to know ES concepts and their implications. This highlights some aspects: on the one hand, the sensitivity of users to environmental issues and, therefore, to the redevelopment project; on the other, a high cultural level, which can be explained with the high concentration of researchers from nearby universities.

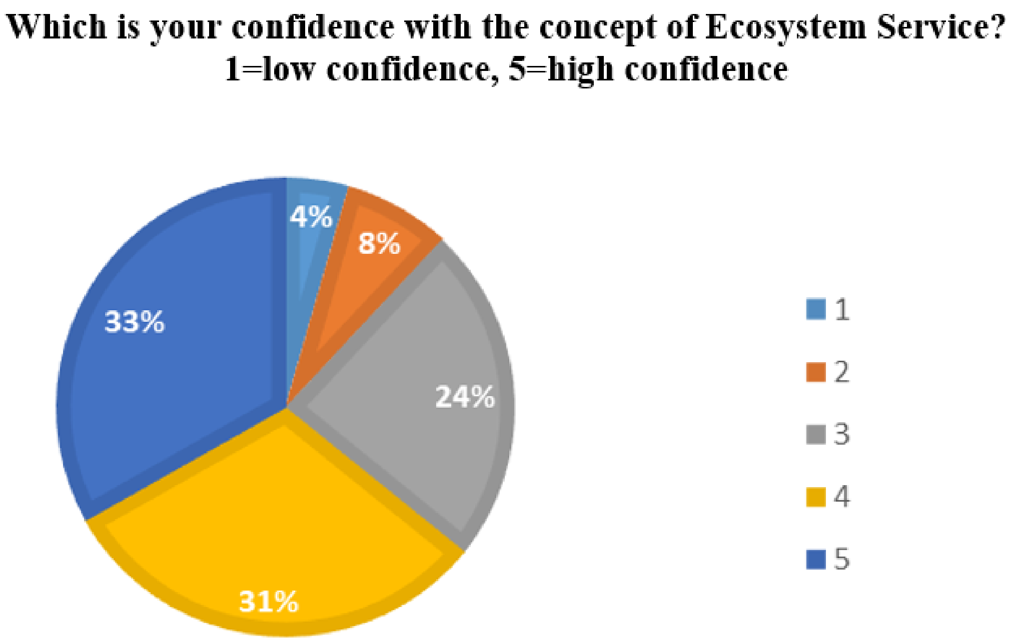


**Fig. 30** Perception and knowledge of the concept of "ecosystem services" among the users who answered the questionnaire.

Moreover, considering the redevelopment project, interesting data emerge: according to 69% of users, there are no nearby green public areas comparable to the one under analysis, where to carry out the same activities – or at least this is the perception. Additionally, few users declared the willingness to walk 500 meters (or more) to find a similar area, a fact that underlines the importance to find a nearby compensation solution, available to users.

**How much are you willing to move to spend time in a similar green area?**

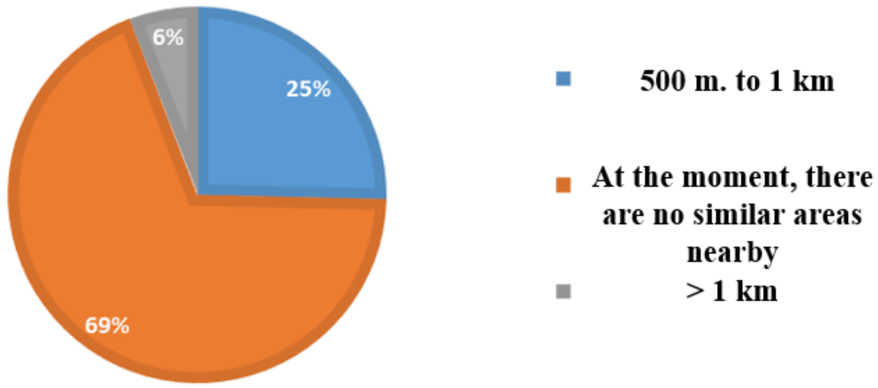


**Fig. 31** Degree of possible mobility of the users who answered the questionnaire.

Finally, another interesting aspect concerns the availability of voluntary tax payment, with the specific purpose of continuing to use the area, thus contributing to its care and maintenance. We proposed monetary intervals (€ 0; € 1-5; € 5-10, more than € 10) on an annual basis, with thresholds derived from similar researches (34). It emerges that over 60% of the users would be willing to pay at least 5 €/year for park maintenance, a sign of the green area's importance.

**How much are you willing to raise your taxes to keep the area?**

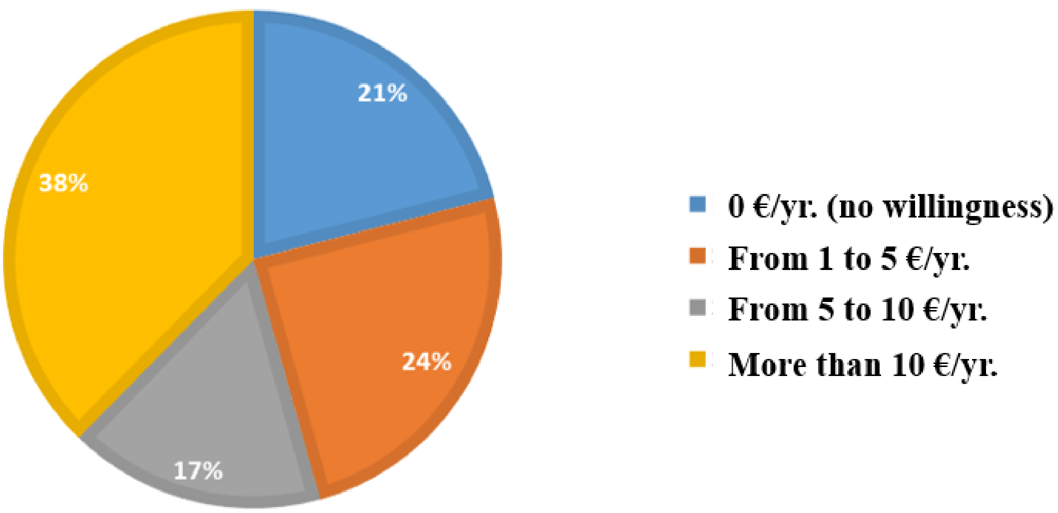


**Fig. 32** Possibility of self-taxing among users who answered the questionnaire in order to be able to continue using the area.

Therefore, several interesting data emerge from the questionnaire. Above all, a strong sensibility and perception of the green area among citizens and a good knowledge of the ES concept. Furthermore, since the beginning, our activity has been followed with high interest by most of the involved stakeholders (citizens, public bodies) – a sign of an important desire to participate in the decision-making processes since the strong impact that the redevelopment plan will have on the whole district. The responses represent an essential database that will identify new areas in which to implement compensation works.

### 5.6. Conclusions

We aimed at analysing ES provision granted by an urban green area, introducing a new evaluation framework to assess ES from a systemic and global point of view, not limiting our evaluation only to separate components (e.g., soil or trees). This new approach considers the principal components that contribute to ES provision in urban and peri-urban environments. To obtain an overall assessment, we selected and tested a set of different scientific tools useful for the purpose, applying the methodology to a specific case study in Milan. Indeed, we were involved in a debated construction project regarding constructing new buildings in an urban park to evaluate this environmental impact. However, the construction was already undergoing when our analysis began: therefore, we had to rebuild the pre-intervention situation to quantify original ES levels. Results show that, in light of the soil net consumption and the loss of green areas, it is necessary to plan and implement a series of compensation activities with a more significant impact than those currently foreseen, both quantitative and qualitative terms. These results are confirmed by the simulation of the ES provision in the next 30 years. Compensations must not result in a simple increase in tree number but should guarantee a complete ES supply, for example, ensuring a correct and sustainable water cycle – as required by regional regulations – dealing soil portions, and creating new green spaces readily available to local inhabitants, thus guaranteeing an equal natural capital level in the Municipality.

The case study was a useful test for this systemic methodologic approach, that could be reproposed in other similar area and introduced as alternative to the one currently adopted by Milan municipality that showed its limitations in assessing the value of the green area.

**Appendixes**

**App. 1 UF economic value proposal:**

We propose an economic value of UF the structural and provided ES. The values were obtained using a similar literature analysis.

Since the importance of the area and the tree characteristics, we propose to apply an alternative method of calculation, compared to the one currently adopted by the Municipality of Milan, which applies reductive coefficients that do not fit with the case study.

Therefore, in our analysis, we apply two different methods to obtain a global value of the green area. We call these methods structural and functional values. The structural value is given by the trees' real consistency and can be quantified with the costs that should be bear to replace each element with a similar one, and therefore tends to increase over time. The functional value is instead given by the value of ES that trees guarantee. This value tends to increase over time, too, thanks to the community's growth and development. Various parameters can affect these values, including the correct maintenance and phytosanitary health: e.g., if the percentage of decayed and/or suffering trees grows over time due to biotic or abiotic stress, the overall value will tend to decline. The functional value is given by the sum of the monetary values obtained from the quantification of each ES provided by the green area, obtained from bibliographic economic coefficients. The structural value is given instead following the Council of Tree and Landscape Appraisers (CTLA) (35) methodology:

Basic Value = Replacement Cost + [Basic Price * (TAa-TAr) * Species Value]

Where: Replacement Cost represents the cost of the most developed specimen available in the nursery; Basic Price represents the local average cost per unit of log area (€ per $cm^2$); TAa is the diameter of the trunk at a standard height of 1,30 m of the analysed tree; TAr is the diameter of the trunk at a standard height of 1,30 m of the most developed tree available in nurseries; Species Value is a variable coefficient between 0 and 1 obtained from the International Society of Arboriculture methodology. This calculation is implemented using the I-Tree Eco software. In our case study, the trees' value in the pre-construction area is equal to 272000 euros.

**Carbon storage and sequestration:** The economic value of sequestered and stored carbon can be calculated based on the current US market value of carbon (US EPA 2015) (36) and converted into € at the current exchange rate. For the analysis, the considered value is equal to 161 euros per $CO_2$ ton. Given the 1507 kg/year of carbon sequestered, the associated economic value is equal to € 242,4. The stored carbon instead is equal to 66,4 tons with an economic value of € 10660.

**Atmospheric pollutants:** To quantify the value of the air pollutants removed by trees, we used literature data if available, in particular: € 36354 per ton of ozone; € 5430 per ton of nitrogen dioxide; € 1978 per ton of sulphur dioxide and € 1083 per ton of carbon monoxide. Given the 30,93 kg of pollutants removed, the corresponding economic value is equal to € 821.

**Water run-off:** the avoided run-off value is multiplied by the bibliographic price of € 1,90 per $m^3$ of water intercepted. Given the 83,9 $m^3$ intercepted, the value is equal to € 160.

**App. 2 – List of the herbaceous species found in the area:**

| Family | Species | Exotic origin | Biological form 1 | Biological form 2 | Chorotype | Macro-Chorotype | Herbaceous edges/margins | Lawns |
|---|---|---|---|---|---|---|---|---|
| Asteraceae | *Achillea millefolium* L. | Indigenous | H scap | | Eurosiber. | Europ.-Asiat. | | X |
| Lamiaceae | *Ajuga reptans* L. | Indigenous | Ch rept | H rept | Eurasiat. | Europ.-Asiat. | | X |
| Poaceae | *Anisantha sterilis* (L.) Nevski | Indigenous | T scap | | Medit. Turan. | Europ.-Asiat. | X | |
| Asteraceae | *Bellis perennis* L. | Indigenous | H ros | | Eurasiat. | Europ.-Asiat. | | X |
| Brassicaceae | *Capsella bursa-pastoris* (L.) Medik | Indigenous | H bienn | | Cosmop. | Cosmop. | | X |
| Brassicaceae | *Cardamine hirsuta* L. | Indigenous | T scap | | Cosmop. | Cosmop. | | X |
| Lamiaceae | *Clinopodium vulgare* L. | Indigenous | H scap | | Circumbor. | Europ.-Asiat. | | X |
| Convolvulaceae | *Convolvulus arvensis* L. | Indigenous | G rhiz | | Cosmop. | Cosmop. | | X |
| Poaceae | *Cynodon dactylon* (L.) Pers. | Indigenous | G rhiz | H rept | Cosmop. | Cosmop. | | X |
| Poaceae | *Dactylis glomerata* L. | Indigenous | H caesp | | Paleotemp. | Europ.-Asiat. | | X |
| Apiaceae | *Daucus carota* L. | Indigenous | H bienne | T scap | Paleotemp. | Europ.-Asiat. | | X |
| Asteraceae | *Erigeron annuus* (L.) Desf. | Neophyte | T scap | | N-Americ. | Avventizio | | X |
| Asteraceae | *Erigeron canadensis* L. | Neophyte | T scap | | N-Americ. | Avventizio | | X |
| Geraniaceae | *Erodium cicutarium* (L.) L'Hér. | Indigenous | T caesp | T scap | Subcosmop. | Cosmop. | | X |
| Euphorbiaceae | *Euphorbia maculata* L. | Neofita invasiva | T rept | | N-Americ. | Avventizio | X | X |
| Euphorbiaceae | *Euphorbia peplus* **L.** | Indigenous | T scap | | Cosmop. | Cosmop. | X | |
| Ranunculaceae | *Ficaria verna* Huds. | Indigenous | G bulb | H scap | Eurasiat. | Europ.-Asiat. | | X |
| Rubiaceae | *Galium aparine* L. | Indigenous | T scap | | Eurasiat. | Europ.-Asiat. | X | |
| Geraniaceae | *Geranium molle* L. | Indigenous | H bienn | T scap | Subcosmop. | Cosmop. | | X |
| Araliaceae | *Hedera helix* L. | Indigenous | P lian | | Submedit.-Subatl. | Atlantico | X | |
| Lamiaceae | *Lamium purpureum* L. | Indigenous | T scap | | Eurasiat. | Europ.-Asiat. | | X |
| Poaceae | *Lolium perenne* L. | Indigenous | H caesp | | Circumbor. | Europ.-Asiat. | | X |
| Fabaceae | *Lotus corniculatus L.* | Indigenous | H scap | | Cosmop. | Cosmop. | | X |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Malvaceae | *Malva sylvestris* L. | Indigenous | H scap | T scap | Subcosmop. | Cosmop. | | X |
| Fabaceae | *Medicago lupulina* L. | Indigenous | H scap | | Eurasiat. | Europ.-Asiat. | | X |
| Urticaceae | *Parietaria judaica* L. | Indigenous | H scap | | Euri-Medit. | Medit. s.l. | X | |
| Plantaginaceae | *Plantago lanceolata* L. | Indigenous | H ros | | Cosmop. | Cosmop. | | X |
| Plantaginaceae | *Plantago major* L. | Indigenous | H ros | | Subcosmop. | Cosmop. | | X |
| Poaceae | *Poa compressa* L. | Indigenous | H caesp | | Circumbor. | Boreale | | X |
| Poaceae | *Poa trivialis* L. | Indigenous | H caesp | | Eurasiat. | Europ.-Asiat. | | X |
| Rosaceae | *Potentilla indica* (Andrews) Th. Wolf | Neophyte | H ros | | Asiatica | Avventizio | X | X |
| Asteraceae | *Senecio vulgaris* L. | Indigenous | T scap | | Subcosmop. | Cosmop. | X | |
| Poaceae | *Setaria italica* subsp. *viridis* (L.) Thell. | Cripto-genic | T scap | | Subcosmop. | Cosmop. | X | X |
| Caryophyllaceae | *Silene italica* (L.) Pers. subsp. *italica* | Indigenous | H ros | | Euri-Medit. | Medit. s.l. | X | |
| Caryophyllaceae | *Silene vulgaris* (Moench) Garcke | Indigenous | H scap | | Paleotemp. | Cosmop. | | X |
| Asteraceae | *Sonchus asper* (L.) Hill | Indigenous | H bienn | T scap | Subcosmop. | Cosmop. | X | X |
| Caryophyllaceae | *Stellaria media* (L.) Vill. | Indigenous | H bienn | T rept | Cosmop. | Cosmop. | X | |
| Asteraceae | *Taraxacum sect. Taraxacum* F.H. Wigg. | Indigenous | H ros | | Circumbor.-Cosmop. | Cosmop. | | X |
| Fabaceae | *Trifolium pratense* L. | Indigenous | H scap | | Subcosmop. | Cosmop. | | X |
| Fabaceae | *Trifolium repens* L. | Indigenous | Ch rept | H rept | Subcosmop. | Cosmop. | | X |
| Urticaceae | *Urtica dioica* L. | Indigenous | H scap | | Subcosmop. | Cosmop. | X | |
| Veronicaceae | *Veronica persica* Poir. | Neophyte | T scap | | W-Asiat. | Avventizio | | X |
| Violaceae | *Viola odorata* L. | Indigenous | H ros | | Euri-Medit. | Medit. s.l. | | X |

**App. 3 – I-Tree Eco simulation database:**

| ID | Species | Trunk circ. | Height | Crown Height | Crown Diameter | Missing crown (%) | Land use |
|---|---|---|---|---|---|---|---|
| 1 | *Platanus x acerifolia* | 100,0 | 16,0 | 13,0 | 17,0 | 5,0 | Park |
| 2 | *Cedrus atlantica* | 205,0 | 22,0 | 19,0 | 9,8 | 0,0 | Park |
| 3 | *Cedrus atlantica* | 186,0 | 21,0 | 19,0 | 16,6 | 0,0 | Park |
| 4 | *Cedrus atlantica* | 234,0 | 23,0 | 20,0 | 15,6 | 0,0 | Park |
| 6 | *Acer platanoides* | 67,0 | 7,5 | 4,0 | 5,0 | 5,0 | Park |
| 7 | *Acer platanoides* | 61,0 | 7,5 | 4,0 | 4,5 | 5,0 | Park |
| 8 | *Ailanthus altissima* | 85,0 | 7,0 | 3,5 | 10,5 | 5,0 | Park |
| 9 | *Eriobotrya japonica* | 69,0 | 6,0 | 3,0 | 6,0 | 3,0 | Park |
| 10 | *Betula pubescens* | 85,0 | 10,0 | 2,0 | 3,0 | 90,0 | Park |
| 12 | *Populus nigra* | 177,0 | 18,0 | 16,5 | 5,0 | 3,0 | Park |
| 13 | *Populus nigra* | 235,0 | 19,0 | 17,5 | 5,5 | 3,0 | Park |
| 21 | *Cedrus atlantica* | 103,0 | 4,5 | 3,5 | 6,0 | 5,0 | Park |
| 32 | *Magnolia grandiflora* | 116,2 | 8,0 | 7,8 | 6,6 | 3,0 | Park |
| 33 | *Magnolia grandiflora* | 103,7 | 8,0 | 7,8 | 6,7 | 3,0 | Park |
| 34 | *Magnolia grandiflora* | 88,0 | 6,0 | 7,8 | 6,0 | 3,0 | Park |
| 35 | *Cedrus atlantica* | 110,0 | 4,0 | 1,5 | 6,7 | 0,0 | Park |
| 36 | *Cercis siliquastrum* | 164,0 | 10,0 | 8,0 | 7,1 | 15,0 | Park |
| 37 | *Thuja occidentalis* | 59,7 | 8,0 | 8,0 | 3,1 | 0,0 | Park |
| 38 | *Thuja occidentalis* | 56,5 | 6,5 | 6,5 | 2,6 | 0,0 | Park |
| 39 | *Platanus x acerifolia* | 235,0 | 20,0 | 17,0 | 7,8 | 10,0 | Park |
| 40 | *Platanus x acerifolia* | 130,0 | 17,0 | 13,0 | 9,2 | 10,0 | Park |
| 41 | *Platanus x acerifolia* | 151,0 | 18,0 | 14,0 | 8,8 | 10,0 | Park |
| 42 | *Liquidambar styraciflua* | 31,4 | 4,5 | 2,5 | 2,1 | 25,0 | Park |
| 43 | *Robinia pseudoacacia* | 45,0 | 7,0 | 5,0 | 8,3 | 15,0 | Park |
| 44 | *Robinia pseudoacacia* | 40,0 | 6,0 | 4,0 | 7,9 | 10,0 | Park |
| 45 | *Quercus rubra* | 9,0 | 3,0 | 2,0 | 3,0 | 10,0 | Park |
| 46 | *Quercus rubra* | 8,0 | 3,0 | 1,5 | 3,6 | 10,0 | Park |
| 47 | *Tilia x europaea* | 28,3 | 5,0 | 3,0 | 3,8 | 20,0 | Park |
| 48 | *Tilia x europaea* | 31,4 | 5,0 | 3,0 | 3,6 | 15,0 | Park |
| 49 | *Tilia x europaea* | 28,3 | 5,0 | 3,0 | 3,8 | 40,0 | Park |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 50 | *Tilia x europaea* | 125,7 | 12,0 | 8,0 | 4,9 | 0,0 | Park |
| 51 | *Tilia x europaea* | 110,0 | 12,0 | 8,0 | 4,1 | 0,0 | Park |
| 52 | *Ulmus laevis* | 120,0 | 15,0 | 12,0 | 10,5 | 5,0 | Park |
| 53 | *Ulmus laevis* | 219,9 | 16,0 | 13,0 | 12,0 | 5,0 | Park |
| 54 | *Ulmus laevis* | 157,1 | 14,0 | 11,0 | 7,2 | 5,0 | Park |
| 55 | *Ulmus laevis* | 47,1 | 10,0 | 8,0 | 7,8 | 5,0 | Park |
| 56 | *Ulmus laevis* | 141,4 | 13,0 | 11,0 | 9,1 | 5,0 | Park |
| 57 | *Ulmus laevis* | 141,4 | 13,0 | 10,0 | 6,5 | 5,0 | Park |
| 58 | *Populus nigra* | 235,0 | 21,0 | 20,0 | 3,5 | 5,0 | Park |
| 59 | *Populus nigra* | 220,0 | 21,0 | 20,0 | 3,7 | 5,0 | Park |
| 60 | *Populus nigra* | 288,0 | 22,0 | 21,0 | 3,6 | 5,0 | Park |
| 61 | *Tilia x europaea* | 18,8 | 4,0 | 2,0 | 2,0 | 70,0 | Park |
| 62 | *Tilia x europaea* | 15,7 | 3,5 | 2,0 | 1,8 | 30,0 | Park |
| 63 | *Tilia x europaea* | 146,0 | 15,0 | 12,0 | 5,2 | 5,0 | Park |
| 64 | *Tilia x europaea* | 115,0 | 14,0 | 11,0 | 5,1 | 5,0 | Park |
| 65 | *Tilia x europaea* | 126,0 | 12,0 | 9,5 | 4,4 | 20,0 | Park |
| 66 | *Tilia x europaea* | 25,1 | 5,0 | 3,0 | 3,5 | 70,0 | Park |
| 67 | *Tilia x europaea* | 25,1 | 5,0 | 3,0 | 3,7 | 70,0 | Park |
| 68 | *Cercis siliquastrum* | 150,7 | 8,0 | 7,0 | 4,9 | 10,0 | Park |
| 69 | *Prunus armeniaca* | 15,7 | 3,0 | 2,2 | 2,6 | 0,0 | Park |
| 70 | *Tilia x europaea* | 31,4 | 3,0 | 1,5 | 3,5 | 0,0 | Park |
| 71 | *Tilia x europaea* | 18,8 | 3,0 | 1,5 | 3,0 | 0,0 | Park |
| 72 | *Tilia x europaea* | 18,8 | 3,0 | 1,5 | 2,9 | 0,0 | Park |
| 73 | *Tilia x europaea* | 15,7 | 3,0 | 1,5 | 2,9 | 0,0 | Park |
| 74 | *Tilia x europaea* | 22,0 | 3,0 | 1,5 | 2,8 | 0,0 | Park |
| 75 | *Tilia x europaea* | 31,4 | 3,0 | 1,5 | 3,1 | 0,0 | Park |
| 76 | *Acer ginnala* | 22,5 | 6,0 | 6,0 | 2,8 | 10,0 | Park |
| 77 | *Ginkgo biloba* | 18,0 | 5,0 | 2,5 | 3,2 | 0,0 | Park |
| 78 | *Celtis australis* | 144,5 | 21,0 | 18,0 | 9,2 | 5,0 | Park |
| 79 | *Celtis australis* | 141,4 | 20,0 | 17,0 | 9,0 | 5,0 | Park |
| 80 | *Celtis australis* | 138,2 | 18,0 | 15,0 | 8,8 | 5,0 | Park |
| 81 | *Populus nigra* | 81,7 | 16,0 | 4,0 | 4,2 | 5,0 | Park |
| 82 | *Populus nigra* | 91,1 | 15,0 | 4,0 | 4,8 | 5,0 | Park |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 83 | *Populus nigra* | 157,1 | 18,0 | 4,0 | 6,1 | 5,0 | Park |
| 84 | *Prunus pissardii* | 87,0 | 7,0 | 1,0 | 6,4 | 5,0 | Park |
| 85 | *Populus nigra* | 150,8 | 16,0 | 4,0 | 6,8 | 5,0 | Park |
| 86 | *Robinia pseudoacacia* | 79,5 | 12,0 | 3,0 | 7,2 | 5,0 | Park |
| 87 | *Quercus rubra* | 163,4 | 18,0 | 10,0 | 7,1 | 5,0 | Park |
| 88 | *Quercus rubra* | 160,2 | 17,0 | 10,0 | 7,7 | 5,0 | Park |
| 89 | *Quercus rubra* | 106,8 | 15,0 | 9,0 | 7,4 | 5,0 | Park |
| 90 | *Quercus rubra* | 213,6 | 20,0 | 11,0 | 7,0 | 5,0 | Park |
| 91 | *Quercus rubra* | 147,7 | 20,0 | 12,0 | 7,1 | 5,0 | Park |
| 92 | *Quercus rubra* | 138,2 | 16,0 | 12,0 | 7,3 | 5,0 | Park |
| 93 | *Quercus rubra* | 94,2 | 15,0 | 10,0 | 7,0 | 5,0 | Park |
| 95 | *Fagus sylvatica* | 86,0 | 7,0 | 7,0 | 5,2 | 20,0 | Park |
| 96 | *Fagus sylvatica* | 75,0 | 6,5 | 6,5 | 4,7 | 10,0 | Park |
| 97 | *Prunus pissardii* | 27,5 | 4,0 | 4,0 | 2,7 | 30,0 | Park |
| 98 | *Carpinus betulus* | 14,0 | 3,5 | 3,5 | 2,4 | 10,0 | Park |
| 99 | *Carpinus betulus* | 19,8 | 3,5 | 3,5 | 2,3 | 10,0 | Park |
| 100 | *Carpinus betulus* | 14,0 | 3,5 | 3,5 | 2,4 | 10,0 | Park |
| 101 | *Carpinus betulus* | 11,0 | 3,5 | 3,5 | 2,1 | 5,0 | Park |
| 102 | *Carpinus betulus* | 15,0 | 3,5 | 3,5 | 2,5 | 10,0 | Park |
| 103 | *Carpinus betulus* | 12,0 | 3,5 | 3,5 | 2,4 | 10,0 | Park |
| 104 | *Carpinus betulus* | 19,0 | 3,5 | 3,5 | 2,2 | 15,0 | Park |
| 105 | *Carpinus betulus* | 14,0 | 3,5 | 3,5 | 2,0 | 15,0 | Park |
| 106 | *Carpinus betulus* | 14,0 | 3,5 | 3,5 | 2,1 | 5,0 | Park |
| 107 | *Carpinus betulus* | 14,0 | 3,5 | 3,5 | 2,3 | 10,0 | Park |
| 108 | *Prunus pissardii* | 10,0 | 3,0 | 3,0 | 1,8 | 15,0 | Park |
| 109 | *Prunus pissardii* | 10,0 | 3,5 | 3,5 | 2,0 | 5,0 | Park |
| 110 | *Prunus pissardii* | 10,0 | 3,0 | 3,0 | 1,9 | 5,0 | Park |
| 111 | *Prunus pissardii* | 10,0 | 3,0 | 3,0 | 1,9 | 10,0 | Park |
| 112 | *Prunus pissardii* | 19,0 | 4,0 | 4,0 | 2,5 | 5,0 | Park |
| 113 | *Populus nigra* | 230,0 | 22,0 | 19,0 | 8,0 | 5,0 | Park |
| 114 | *Populus nigra* | 178,0 | 20,0 | 17,0 | 6,5 | 0,0 | Park |
| 115 | *Populus nigra* | 227,0 | 21,0 | 18,0 | 8,8 | 0,0 | Park |
| 116 | *Populus nigra* | 234,0 | 21,0 | 18,0 | 9,2 | 0,0 | Park |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 117 | *Populus nigra* | 160,2 | 21,0 | 18,0 | 10,9 | 0,0 | Park |
| 118 | *Populus nigra* | 179,1 | 21,0 | 18,0 | 7,9 | 0,0 | Park |
| 119 | *Populus nigra* | 185,4 | 20,0 | 4,0 | 8,0 | 5,0 | Park |
| 120 | *Populus nigra* | 157,1 | 22,0 | 4,0 | 7,5 | 5,0 | Park |
| 121 | *Populus nigra* | 119,4 | 21,0 | 4,0 | 7,5 | 5,0 | Park |
| 122 | *Populus nigra* | 160,2 | 20,0 | 4,0 | 4,5 | 5,0 | Park |
| 123 | *Populus nigra* | 153,9 | 20,0 | 4,0 | 5,0 | 5,0 | Park |
| 124 | *Populus nigra* | 175,9 | 20,0 | 4,0 | 6,0 | 5,0 | Park |
| 125 | *Populus nigra* | 175,9 | 18,0 | 4,0 | 6,5 | 5,0 | Park |
| 126 | *Carpinus betulus* | 175,9 | 16,0 | 5,0 | 3,0 | 3,0 | Park |
| 127 | *Populus nigra* | 197,9 | 20,0 | 4,0 | 10,0 | 3,0 | Park |
| 128 | *Platanus x acerifolia* | 259,0 | 24,0 | 21,0 | 18,3 | 0,0 | Park |
| 129 | *Ficus carica* | 40,0 | 6,0 | 3,0 | 5,7 | 5,0 | Park |
| 130 | *Populus nigra* | 194,8 | 21,0 | 4,0 | 7,8 | 0,0 | Park |
| 131 | *Prunus laurocerasus* | 45,0 | 5,0 | 1,0 | 6,7 | 0,0 | Park |
| 132 | *Populus nigra* | 179,1 | 18,0 | 4,0 | 5,9 | 5,0 | Park |
| 133 | *Populus nigra* | 185,4 | 19,0 | 4,0 | 8,0 | 3,0 | Park |
| 134 | *Populus nigra* | 163,4 | 19,0 | 4,0 | 6,0 | 3,0 | Park |
| 135 | *Cercis siliquastrum* | 60,0 | 7,0 | 4,0 | 5,0 | 5,0 | Park |
| 136 | *Tilia x europaea* | 55,0 | 12,0 | 2,0 | 6,0 | 5,0 | Park |
| 137 | *Populus nigra* | 185,4 | 17,0 | 4,0 | 6,5 | 5,0 | Park |
| 138 | *Populus nigra* | 100,5 | 14,0 | 3,0 | 8,0 | 5,0 | Park |
| 139 | *Celtis australis* | 37,6 | 8,0 | 1,0 | 5,0 | 3,0 | Park |
| 140 | *Mespilus germanica* | 70,0 | 6,0 | 2,0 | 5,5 | 3,0 | Park |
| 141 | *Trachycarpus fortunei* | 8,0 | 4,0 | 0,5 | 5,0 | 3,0 | Park |
| 142 | *Magnolia x soulangeana* | 67,0 | 3,0 | 3,0 | 5,0 | 3,0 | Park |
| 143 | *Magnolia x soulangeana* | 59,0 | 3,0 | 2,5 | 5,0 | 3,0 | Park |
| 144 | *Populus nigra* | 49,0 | 15,0 | 4,0 | 5,2 | 0,0 | Park |
| 145 | *Populus nigra* | 191,6 | 21,0 | 4,0 | 5,6 | 0,0 | Park |
| 146 | *Populus nigra* | 194,8 | 20,0 | 4,0 | 5,5 | 10,0 | Park |
| 147 | *Populus nigra* | 182,2 | 21,0 | 4,0 | 5,0 | 5,0 | Park |
| 148 | *Populus nigra* | 251,3 | 22,0 | 4,0 | 6,5 | 3,0 | Park |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 149 | *Populus nigra* | 182,2 | 18,0 | 4,0 | 3,5 | 3,0 | Park |
| 150 | *Populus nigra* | 131,9 | 18,0 | 4,0 | 3,0 | 5,0 | Park |
| 151 | *Populus nigra* | 166,5 | 21,0 | 4,0 | 3,6 | 5,0 | Park |
| 152 | *Fagus sylvatica* | 94,0 | 14,0 | 14,0 | 9,5 | 5,0 | Park |
| 153 | *Prunus avium* | 157,0 | 11,0 | 3,0 | 3,0 | 20,0 | Park |
| 154 | *Populus nigra* | 169,6 | 17,0 | 4,0 | 3,0 | 10,0 | Park |
| 155 | *Tilia x europaea* | 180,0 | 18,0 | 3,0 | 10,0 | 5,0 | Park |
| 157 | *Magnolia x soulangeana* | 40,0 | 6,0 | 4,0 | 4,0 | 0,0 | Park |
| 158 | *Magnolia x soulangeana* | 32,0 | 6,0 | 4,0 | 3,8 | 0,0 | Park |

**App. 4 Questionnaire:**

As part of the ES quantification offered by the former green area, we ask for your opinion to understand citizens perception regarding urban green areas. The survey is carried out by University of Milan. It will take you about 10 to 15 minutes to complete it.

Privacy

The data provided will be used for research activities and are collected anonymously and in aggregate pursuant to and for the purposes of art. 13 (Title III - General rules for data processing), of Legislative Decree n.196 / 03 30-06-03 "code regarding the processing of personal data".

Your contribution will be precious!

QUESTIONS INTRODUCTORY PART

1) Gender: F; M.

2) Age (years): <25; between 25-45; between 46 and 65; greater than 66

3) Educational level:

- Primary education (elementary school)

- Lower secondary education (middle school license)

- Higher secondary education (high school diploma, vocational institute ...)

- Tertiary education (post-diploma professional training courses, old system degree, three-year degree, master's degree)

- Other, e.g., PhD, research fellowships, post-graduate master's courses.

4) Town Hall of residence or Postal Code or indicate if you are not resident in the Municipality of Milan.

5) Do you have at least one or more children? Yes; No

6) Do you have a dog? Yes; No

7) Main sector of employment/study/interest:

8) How well do you know the term "ECOSYSTEM SERVICES", assigning a rating from 1 (not at all) to 5 (very)

9) Were you a frequenter of the former green area or, more generally, do you know the area well? Yes; No

Questions to those who answered "yes" to question "9"

9.a) Which of the following categories do you belong to (or do you feel you are mainly related)

- Activist-Associate in organizations/associations/committees

- Common citizen using the area

- University employee/student

- Other

9.b) How often did you visit the area?

- Once a year or less

- At least once a month

- At least once a week

- Nearly every day

9.c) What was the main reason of visit?

- Occasional/casual visitor

- User associated with proximity to the place of study/work

- User associated with proximity to the place of residence

9.d) How much was the safety degree you perceived within the area?

- Very low - Low - Medium - Medium high - High

9.e) How much would you be willing to travel to carry out the activities you previously did there?

- Between 500 m and 1 km

- More than 1 km

- There is no nearby area with those characteristics that can replace it

9.f) Would you have been willing to increase your annual taxes by X euros as a contribution to the use of the area?

- NO (zero euro)

- YES, from 1 to 5 euros

- YES, from 5 to 10 euros

- YES, more than 10 euro

9.g) This figure highlights four categories of ecosystem services: SUPPLY (A), REGULATION (R), SUPPORT (S), CULTURAL (C).


Write them in order from 1 to 4, from the most important to the least, according to the categories of ecosystem services that were offered for you by the area.

10. Indicate how much you agree or disagree with the following statements by assigning a rating from 1 (not at all) to 5 (very much). The statements refer to the former green area.

10.a) Attending this area helped me to clear my mind. 1-2-3-4-5

10.b) I got a better perspective on my life when I enjoyed that place. 1-2-3-4-5

10.c) Visiting this area made me feel connected with nature. 1-2-3-4-5

10.d) When I was in that place, I felt part of something bigger than myself. 1-2-3-4-5

10.e) That place was almost part of me. 1-2-3-4-5

10.f) I felt a sense of belonging to that place. 1-2-3-4-5

10.g) I have many memories related to that place. 1-2-3-4-5

10.h) I missed that place when I was away from it for a long time. 1-2-3-4-5

10.i) Seeing/attending that place made me learn about nature. 1-2-3-4-5

10.j) I have met people by visiting/frequenting that place. 1-2-3-4-5

10.k) I felt I could contribute to the care of that place. 1-2-3-4-5

10.l) I was struck by the beauty of that place. 1-2-3-4-5

10.m) It was an inspiring place. 1-2-3-4-5

10.n) Visiting/Frequenting that place made me feel healthier. 1-2-3-4-5

10.o) Visiting/Frequenting that place made me feel free. 1-2-3-4-5

Part of the questionnaire dedicated to everyone

11) What kind of green areas do you visit most frequently?

- Small neighbourhood gardens or green areas in the city centre

- Green areas in peri-urban areas

- Natural or naturalistic parks

12) How often do you visit urban green areas?

- Once a year or less

- About once a year

- At least once a month

- At least once a week

- Nearly every day

12) Why do you mostly visit green areas in the city?

- I mainly go with children and/or dogs

- I go to distract myself, relax, have fun etc.

- They are transit areas

13) Is it important that there are trees in urban green areas? Yes, No

14) Is it important that there are several trees in urban green areas? Yes, No

15) Would you be willing to increase your annual taxes by X euros as a contribution for the use of green areas?

- NO (zero euro)

- YES, from 1 to 5 euros

- YES, from 5 to 10 euros

- YES, more than 10 euros

16) Should more trees be planted in urban green areas? Yes; No

17) According to the figure there are four categories of ecosystem services: SUPPLY (A), REGULATION (R), SUPPORT (S), CULTURAL (C).


Which categories do TREES contribute most to offering services in an urban green area? Sort them from 1 to 4, from the most important to the least, according to your point of view

18) In the figure there are four categories of ecosystem services: SUPPLY (A), REGULATION (R), SUPPORT (S), CULTURAL (C).


Which the categories of ecosystem services should be considered to estimate the ECONOMIC VALUE of an urban green area? Write them in order of 1 to 4, from the most important to the least, in your opinion.

19) Do you think that COVID-19 pandemic has increased the importance and need to use urban green areas? Yes, No

20) Regarding COVID-19 pandemic, do you think it has increased the economic value of urban green areas? Yes, No

21) Indicate how much you disagree or agree with the following statements by assigning a rating from 1 (not at all) to 5 (very much).

21.a) I perceive my neighbourhood as a polluted area compared to the average of the other areas I frequent in the city. 1-2-3-4-5

21.b) I would be willing to use public transport and bicycle more often for my trips around the city. 1-2-3-4-5

21.c) I would give up the use of cars in the city, if there were more connected cycle paths, safe roads and with trees. 1-2-3-4-5

22.d) I would give up areas with parking availability near my home/office in order to have more green areas in the city.

22.e) The area I live in has green areas that meet my needs.

22.f) Urban green areas are neglected places.

22.g) Thanks to the increase in urban green areas, the quality of my life would improve.

22.h) Prior the construction of new green areas, I would like an inclusive way to share and communicate projects.

22.i) I would be willing to pay annual taxes in relation to my income to improve green surface, the care and the quality of the existing green in my neighbourhood.

22.j) The compensation for an urban green area must be planned within a radius of 500 meters from the boundaries of the area that was decommissioned.

22.k) The compensation work for an urban green area, which is being decommissioned, can be planned in an area that is several km away (over 1 km) from the area that was abandoned.

22.l) The compensation work for an urban green area, which is closed, must necessarily have an area equal to or greater than the previous one.

22.m) The compensation work for an urban green area must necessarily have at least the same services (e.g., number of benches, trees) offered by the previous one.

22.n) Seeing/frequenting green areas in the city allows you to free your mind.

22.o) I get a better perspective on my life when I enjoy urban green areas.

22.p) Seeing/attending green areas in the city allows me to connect with nature.

22.q) When I am in urban green areas, I feel part of something bigger than myself.

22.r) The green areas of my city are part of me.

22.s) I feel a sense of belonging to green areas in my city.

22.t) I have many memories related to the green areas of my city.

22.u) I miss the green areas of my city when I am far from it.

22.v) Seeing/frequenting urban green areas made me learn about nature.

22.w) I met people by visiting/frequenting the green areas of my city.

22.x) I feel I can contribute to the care in the green areas of my city.

22.y) I am struck by the beauty of the green areas in my city.

22.v) The green areas of my city are a source of inspiration.

22.I) Seeing/attending the green areas of my city makes me feel healthier.

22.II) Seeing/attending the green areas of my city makes me feel freer.

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# 6.Other academic activities

**Chapter Introduction**

The PhD period has been a precious time, not only in regards of the researches presented in this thesis, but also regarding all the other academic activities conducted in the last three years. This chapter presents a set of different activities developed during the three-year period.

The first part of the chapter hosts a paper – "GLORIFY: a new forecasting system for rice grain quality in Northern Italy" – published on European Journal of Agronomy (97, 2018, 70-80 - current Impact Factor: 3.726). The paper was the result of my Master thesis activity and was finished in the first part of my PhD period and it represents one of the first forecasting model capable to foresee both quality and quantity in rice production. Thanks to this research activities, in 2017 I won the third prize at the European Environmental Agency's competition "Farming by Sat", aimed at awarding the best technological solutions to improve agriculture and decrease its environmental impact.

After the published paper, the chapter presents a short communication submitted to Sustainability in 2020 regarding Opera 18, a project aimed at spreading agroecology concepts and practices between Italian farmers.

Moreover, thanks to a wide academic network, I was able to acquire competences in several disciplines and to get in touch with the international research panorama. Among others, the principal experiences and results are here reported. I would like to underline the active involvement – thanks to the help of professor Bocchi and Ingegnoli – in the Planetary Health Alliance (PHA), a no-profit Harvard-based organization which aims at sustainable development. The first results of my researches were accepted at PHA's annual conference – Stanford University, 2019 –, and from there I was involved in the new-born Southern Europe PHA Hub – called PlaHNet. Other important achievements regard the presentations at the FAO World Forum on Urban Forest – Mantova, 2018 – and the poster presentation at the 2nd Agroecology Europe meeting.

European Journal of Agronomy 97 (2018) 70–80

Contents lists available at ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

# 6.1 GLORIFY: a new forecasting system for rice grain quality in Northern Italy

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**Abstract**

A reliable forecast of the pre-harvest grain quality is requested by stakeholders in the rice sector, which is increasingly oriented to the achievement of superior standards to meet the market demand. Despite its economic importance, very few simulation models of the qualitative aspects of rice productions including the effects of weather conditions and farming practices are available. This paper presents GLORIFY, a forecasting system targeting the simulation of head rice yield (HRY), which represents the main determinant of rice market price at global level. A new HRY model was developed using experimental data collected in Northern Italy in 2006-2013 and referred to Loto (*japonica*) and Gladio (*tropical japonica*) cultivars, and it was coupled to the WARM rice simulator. Historical simulations were then performed in the period 1994-2013 to reproduce observed HRY variability, with model outputs and weather variables used as independent variables to build multi-regression models. At field level, model performances denoted a good agreement between observed and simulated HRY ($R^2$ and modelling efficiency in the range 0.73-0.93). At province level, best results were obtained for Loto variety, as the regression model was able to explain 78% of the HRY variability, with a root mean square error (RMSE) of 0.77%. The model accuracy slightly decreased when leave-one-out cross-validation was applied ($R^2$=0.61, RMSE=1.04%). The present study lays the basis for a reliable estimation of HRY variability under different management and weather conditions.

**Keywords**: grain filling, head rice yield, milling quality, night-time air temperature, WARM

### 6.1.1 Introduction

Crop yield forecasting systems (CYFSs) based on simulation models are adopted worldwide to provide in-season estimates of the production of staple food crops (de Wit and van Diepen, 2007; Kogan et al., 2013; Bregaglio et al., 2015; Pagani et al., 2017). CYFSs rely on the outputs of crop models, which are coupled with databases containing weather and soil data in the areas of interest (e.g., the Crop Growth Monitoring Systems of the European Commission, Supit et al., 2010; the Famine Early Warning System of the United States Agency for International Development, http://www.fews.net; the General Large-Area Model for annual crops, Challinor et al., 2004). Currently, CYFSs focus on the simulation of potential and attainable yields (van Ittersum and Rabbinge, 1997; Bezuidenhout and Singels, 2007a, b, Mavromatis, 2014), and progresses in the last decades would allow to consider abiotic and biotic stresses on crops (e.g., the impact of fungal diseases, El Jarroudi et al., 2012; Bregaglio and Donatelli, 2015a).

Despite its paramount importance, the annual variability of the qualitative aspects of crop productions, which are also affected by climatic conditions and farmers management, is not targeted yet by current CYFSs. This represents an urgent need both in developing countries, to forecast and face critical situations for global food security, and in most economically wealthy nations, where farmers are forced to reach superior quality standards to respect the national and continental policies while meeting the consumers' preferences (Tesio et al., 2014). In these perspectives, grain buyers and millers are interested to have access to timely information before crop harvest, the former to purchase high-quality commodities at the best price, the latter to schedule the length of the milling season to maximize business profitability (Bezuidenhout and Singels, 2007a, b; Lee et al., 2013). Despite Italy is the first rice producer in EU-27 and the fourth largest rice exporting country at global level, the national production is undermined by the recent decrease of the incentives from Common Agricultural Policy to rice growers and by the increasing market competition with low-price exporting countries (Griglione et al., 2015). Furthermore, the expected increase in thermal regimes and in the occurrence of weather extremes due to climate change represent an additional threat to Italian rice growers, as it may cause severe decays in grain quality and then in market value (Cappelli et al., 2014). National breeding programs aimed at enhancing the quality of rice productions were thus recently funded for *japonica* – mainly with large, short/long sized and soft cooking, used in the domestic market – and *tropical japonica* cultivars – with long, not sticky grain, for export. Italian breeders are thus mainly focusing on the improvement of milling quality, cooking properties and nutritive characteristics of rice productions (Russo and Callegarin 1997), and on the certification of the supply chain, supporting the implementation of low impact agronomic practices (i.e., organic rice and Protected Geographical Indication rice cultivars, Griglione et al., 2015). Among the qualitative aspects of rice grain, head rice yield (HRY, the relative weight presence of largely intact kernels, also referred to as whole grain, after milling), plays the major role in determining the global market price (Siebenmorgen et al., 2013). HRY is therefore recognized as the key indicator of milling quality, which mainly depends on weather conditions during the grain filling period, on grain moisture content at harvest and on management of post-harvest operations as drying and storage conditions.

Two main reasons limited so far the realization of a model-based CYFS simulating rice quality: (i) the lack of experimental data, intended as reference observations to calibrate and evaluate the models at field level and as time series of official statistics to validate the performance of CYFSs on large area and (ii) the scarce availability of process-based simulation models (Jamieson et al., 1998; Bertin et al., 2010). Indeed, the development of such models is recognized as a priority to improve rice simulators (Porter and Semenov, 2005; Schaap et al., 2013), since most of the available modelling approaches reproduce the impact of meteorological variables (e.g., air temperature, rainfall, wind speed and relative humidity) on grain composition (e.g., protein and starch content) via empirical functions (Lee et al., 2013; Cappelli et al., 2018).

This study presents a new CYFS, named Grain quaLity mOdel RIce Forecasting sYstem (GLORIFY), aiming at forecasting the quality of rice productions in Northern Italy. The quality models implemented are calibrated and evaluated at field level and its data and modelling layers are presented, prior to apply it on a historical series of HRY data collected in the study area.

### 6.1.2 Materials and methods

**Characterization of the study area**

The GLORIFY simulation area is the Northern Italian Lombardo-Piemontese district, which accounts for more than 90% of the total national production (Griglione et al., 2015). The semi-rural Pavia province (latitude 45° 11' N, longitude 9° 09' E, altitude 258 m a.s.l.), contributing to the 35% and 18% of the Italian and European total rice area, is selected as the case study. The climate in the area is temperate humid, with high local heterogeneity of pedo-climatic conditions (Fumagalli et al., 2011). Average annual air temperature is about 13.5 °C, ranging from 0-4 °C in winter months, to peaks over 30 °C in summer. Cumulative annual precipitations fluctuate around 750 mm, with two main rainy periods in autumn and spring, and a minimum from July to August. The utilized agricultural land (UAL) is mainly located in the plain area of the Po basin and extends for around 1800 km$^2$, with latitude ranging between 44° 44' N and 45° 21'N and longitude ranging between 8° 31' E and 9° 30' E (Figure 1).

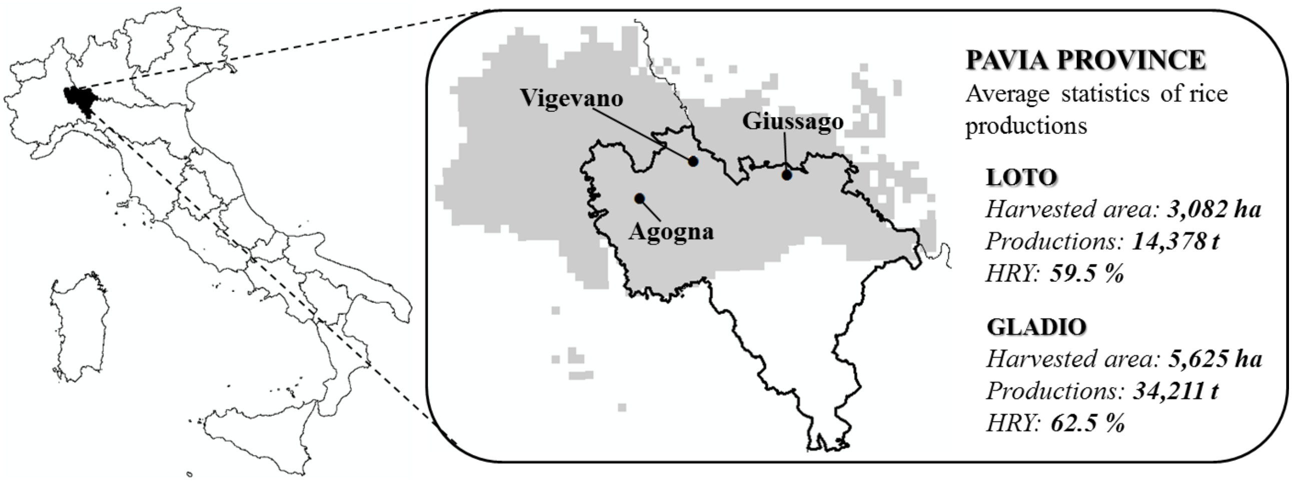


**Figure 1:** Geographic distribution of the study area and average statistics of rice productions in the Pavia province for Loto and Gladio cultivars in the period 2000-2014. The grey area represents the Lombardo-Piemontese rice district; solid circles highlight the three municipalities where long-term simulations were performed.

The cultivation of paddy rice covers about 40% of regional UAL, with maize, forage and grapevine as other major crops. The level of advancement of rice production systems is supervised by the Ente Nazionale Risi (ENR – National Rice Authority; http://www.enterisi.it) and by the Agricultural Research Council (CREA, http://www.crea.gov.it), which are in charge of collecting official statistics on rice harvested area and productivity, providing technical assistance to farmers and certifying the rice cultivars entered in the Italian National Register.

**The data information layer**

GLORIFY relies on a database containing the data to calibrate the crop and quality models at field level, and to perform spatially distributed simulations (Figure 2).

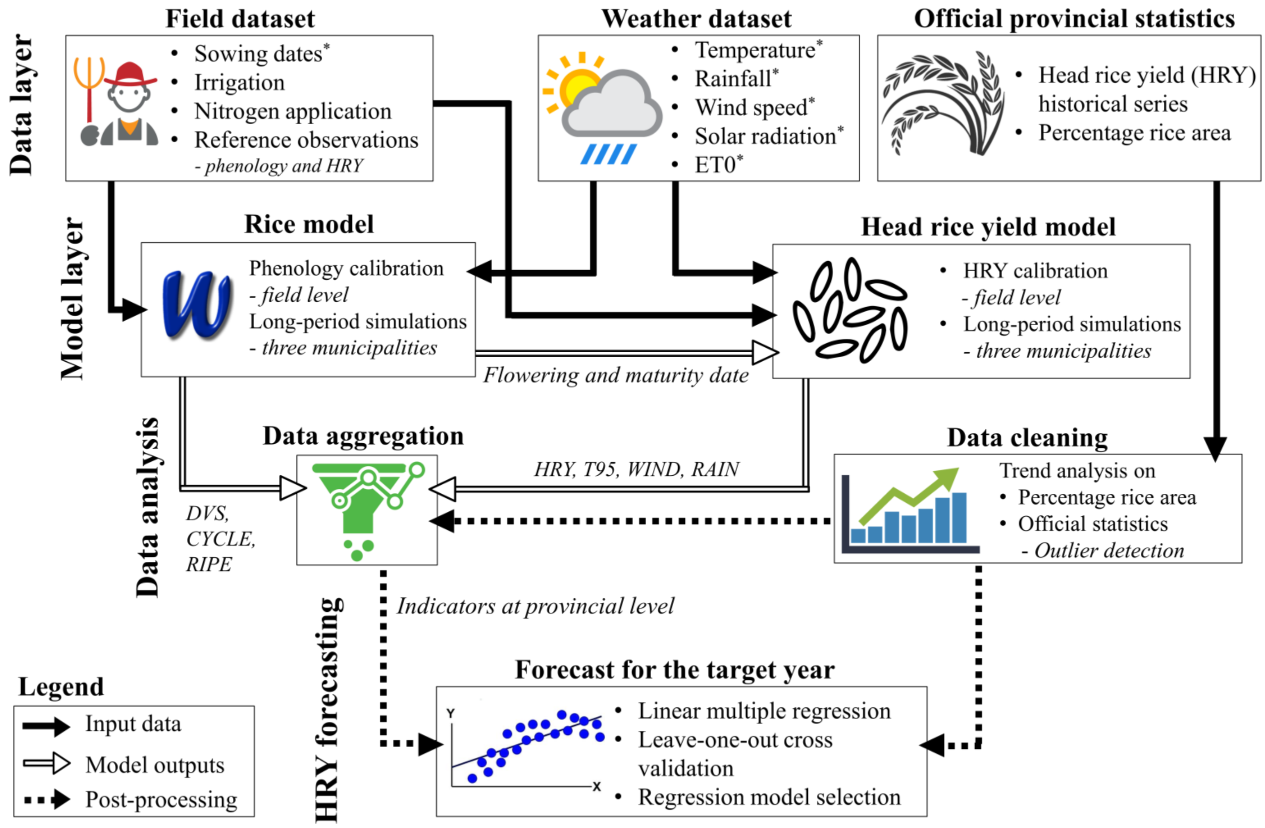


**Figure 2:** Flow diagram of GLORIFY. The forecasting system relies on four information layers: *Data*, *Model*, *Data analysis* and *HRY forecasting*. The *Data* layer is structured in three datasets, corresponding to field, weather and official provincial statistics, providing inputs to the simulation models. The *Model layer* is composed by the WARM rice and HRY simulation models. This layer is in charge of performing the field-level calibration of rice phenology and HRY models and the spatially distributed multi-year simulation; the *Data analysis* layer allows upscaling model results at provincial level and detrending official statistics. In the next layer, this information is used to produce HRY forecasts at rice maturity stage via multiple-linear regression (*HRY forecasting* layer). The asterisks indicate the minimum input data required to run the simulations models. ET0: reference evapotranspiration (mm); DVS: Development Stage Code: 1 = emergence, 2 = flowering, 2.5 = full ripening 3 = physiological maturity; CYCLE: length of the crop cycle; RIPE: length of the ripening period; T95: 95-th percentiles of night-time air temperature frequencies during the late ripening stage; WIND: days with wind speed higher than a critical threshold in late ripening; RAIN: cumulative rainfall in late ripening.

The GLORIFY database integrates data from different sources (*Data* layer), allowing an ease coupling with biophysical models (section 2.3): the *Field* dataset contains experimental field data collected to characterize rice crop development and growth. Available information are phenological observations (date of emergence, flowering and physiological maturity) and HRY data, expressed as percentage of largely intact kernels after milling. This layer also contains data related to the main agricultural management practices adopted by rice growers in the area, i.e., sowing date and irrigation and nitrogen fertilization rates. Alternative irrigation strategies are continuous flooding (i.e., from sowing to milk maturity, with two/three drainages to allow root establishment, weed control and fertilizations), or dry sowing with flooding at third-fourth leaf stage. Nitrogen is mainly applied as urea in two or three events (i.e., 120 and 160 kg N $ha^{-1}$ for Loto and Gladio), in pre-sowing and at beginning of tillering and/or at panicle initiation. The available data are referred to the Italian cultivars Loto and Gladio, as representative of *japonica*- and *tropical japonica*-type cultivars, respectively. The criteria for their selection were their high representativeness within the study area and the availability of historical time series of rice percentage coverage and HRY. Loto (long A grain type, EU standards) is a short cycle cultivar released in 1988, with medium slender grains suitable for parboiling and risotto preparation; Gladio (long B grain type, EU standards) is a medium cycle variety released in 1998, presenting long grains recommended for parboiling, rice salads or side dishes cooking. The data of the experimental trials included in the *Field* dataset were collected by the University of Milan and the ENR in several sites in the period 1990-2013 (Confalonieri et al., 2009b; Cappelli et al., 2014).

The *Official provincial statistics* dataset contains the historical statistics of HRY and rice harvested areas in the period 1994-2013 for Loto and 1999-2013 for Gladio. The database is meant to be extensible with new cultivars.

The *Weather* dataset layer contains daily minimum and maximum air temperatures (°C), rainfall (mm), wind speed (m $s^{-1}$) and reference evapotranspiration (mm) in the period 1990-2013, collected by the weather stations of the Regional Agency for Environmental Protection (ARPA), placed close to the experimental fields. Daily global solar radiation (MJ $m^{-2}$ $d^{-1}$) was simulated according to Hargreaves formula (Hargreaves and Samani, 1982), since it was not available from the weather stations. Hourly temperature was estimated via the method of Donatelli et al. (2010) based on Campbell (1985). Nighttime air temperatures were defined as the hourly temperatures between sunset and sunrise.

**The GLORIFY modelling solution**

**Simulation of crop development**

The simulation engine of GLORIFY is composed by the WARM rice model (Confalonieri et al., 2009a, Cappelli et al., 2014), which was extensively evaluated in the European rice growing conditions (Confalonieri et al., 2009b), and it is used by the European Community to perform rice yield forecasts at continental level. The simulation of phenological development is performed at hourly time step considering a non-linear, upper-limited response to temperature (Yan and Hunt, 1999). Cumulated growing degree days are converted into a decimal code (i.e., development stage code, DVS) ranging from 0 to 4, where 0 = sowing, 1 = emergence, 2 = flowering, 3 = maturity and 4 = harvest. The thermal time between these phases and the cardinal temperatures for development (i.e., base, optimum and maximum temperature) are model parameters. The floodwater effect is taken into account via a micrometeorological model estimating canopy layer and surface water temperatures at hourly time step based on the energy balance approach, that it allows using temperature at the meristematic apex as input for the simulation of crop development. The estimation of hourly air temperature and global solar radiation is performed on-the-fly via the components AirTemperature (Donatelli et al., 2010) and GSRad (Donatelli et al., 2006), respectively. The model computes aboveground biomass accumulation using a radiation use efficiency approach (Warren Wilson, 1967). Photosynthates are partitioned to the plant organs according to development stage, and leaf area index increase is derived by the daily leaves biomass and a dynamic specific leaf area. Leaf senescence is simulated at daily time step as a function of the thermal time accumulation.

**Simulation of head rice yield**

A new HRY model was developed and used in this study. It is derived by the seminal model by Lanning et al. (2011), who formalized HRY dependence on hourly night-time air temperature during the R8 reproductive stage (late maturity, 83-89 BBCH) (Equation 1).

$$HRY = a_i T_{95}^2 + b_i T_{95} + c_i \qquad [1]$$

where HRY (percentage of largely intact grains after milling, %) is the simulated HRY value; $T_{95}$ (°C) is the 95-th percentiles of night-time air temperature frequencies during the 83-89 BBCH ripening stages; $a_i$, $b_i$, $c_i$ (unitless) are cultivar-specific coefficients. This model does not consider the impact of high windiness and low humidity at sub-optimal temperatures for the starch formation in the early ripening, which are known to markedly influence the final value of HRY (Thompson and Mutters 2006; Ishimaru et al., 2009; Paleari et al., 2017). This led to the definition of a new model considering the impact of rainfall, wind speed and temperature during the early ripening stages (BBCH 65 - 83) on potential HRY (HRYi, Equation 2).

$$HRY_i = \begin{cases} a_i \cdot T_{\min}^2 + b_i \cdot T_{\min} + c_i & if \quad T_{95} \le T_{\min} \\ a_i \cdot T_{95}^2 + b_i \cdot T_{95} + c_i & if \quad T_{\min} < T_{95} \le Topt_{\min} \\ a_i \cdot Topt_{\min}^2 + b_i \cdot Topt_{\min} + c_i & if \quad Topt_{\min} < T_{95} \le Topt_{\max} \\ \left(d_i \cdot T_{95}^2 + e_i \cdot T_{95} + g_i\right) + \\ \left[\left(a_i \cdot Topt_{\min}^2 + b_i \cdot Topt_{\min} + c_i\right) - \left(d_i \cdot Topt_{\max}^2 + e_i \cdot Topt_{\max} + g_i\right)\right] & if \quad T_{95} > Topt_{\max} \end{cases} \qquad [2]$$

where $Topt_{min}$ (°C) and $Topt_{max}$ (°C) are the lowest and highest optimal temperatures for the synthesis of starch in the rice grain; $T_{min}$ (°C) is the minimum temperature for the starch synthesis; $a_i$ (0.607 for Loto, -0.179 for Gladio) $b_i$ (-27.848 for Loto, 8.538 for Gladio) $c_i$ (379.557 for Loto, - 36.153 for Gladio), $d_i$ (-0.397 for Loto, -0.179 for Gladio), $e_i$ (20.585 for Loto, 8.537 for Gladio), $g_i$ (-202.890 for Loto, -0.179 for Gladio) are cultivar-specific coefficients (unitless).

The final value of HRY (HRYc, Equation 3) is computed by decreasing the $HRY_i$ when rainfall (RainC), wind speed (WindyD) and temperature ($T95_{em}$) exceed critical thresholds during the sensitive period after flowering (BBCH 65 - 83).

$$HRY_c = \begin{cases} HRY_i - e & if\ T95_{em} > Topt_{\max} \text{ and } RainC < RainTh \text{ and } WindyD > WindyTh \\ HRY_i & else \end{cases} \qquad [3]$$

where e (%) is a cultivar-specific coefficient representing the HRY reduction due to critical humidity, wind speed and temperature during the early ripening period; $T95_{em}$ (°C) is the 95-th percentiles of night-time air temperature during early maturity; RainC (mm) is the cumulated precipitation in the early maturity period; RainTh (mm) is the minimum threshold of cumulated rainfall triggering HRY decrease; WindyD (day) is the number of days with average wind speed higher than a critical threshold (i.e. 2 m $s^{-1}$); $Windy_{Th}$ (days) is the threshold of windy days beyond which HRY starts decreasing.

The new model and the original model by Lanning et al. (2011) were both used in this study to simulate HRY, and their performances were distinctly evaluated.

**Model calibration and validation**

**Field level simulations**

The field level calibration and validation of simulated rice phenology were carried out on 18 datasets collected in municipalities of the Pavia province (Figure 1, Appendix A, Table A.1). The calibration was performed via trial-and-error, using the minimum squared error between simulated and observed data as objective function. The calibration and validation of the HRY model were carried out on 40 data for each cultivar, equal-randomly split in two independent datasets: one half for calibration and the other half for validation (Appendix A, Table A.2 for Loto and A.3 for Gladio). Since rice in the area is intensively cultivated under continuous flooding, with high fertilization and agrochemical inputs, simulations were performed under non-limiting conditions for water, nutrients, weeds and pests/diseases. The information related to irrigation and fertilization strategies were indeed used to characterize the farmer agricultural management, and to select the experiments where nitrogen was not limiting to rice productions (i.e., 120 - 140 kg $ha^{-1}$ for Loto and 160 - 180 kg $ha^{-1}$ for Gladio).

The model performances were evaluated using the mean absolute error (MAE, minimum and optimum = 0, maximum = + ∞, Schaeffer, 1980; values less than half of the standard deviation of the observations indicate good model performance, Moriasi et al., 2007), the relative root mean squared error (RRMSE, minimum and optimum = 0%, maximum = + ∞%, Jørgensen et al. 1986; the model performances can be rated as excellent when lower than 10% of the mean, good when comprised between 10 and 20% and low if higher than 30%, Jamieson et al., 1991), the modelling efficiency (EF, minimum = - ∞ , optimum and maximum = 1, Nash and Sutcliffe, 1970; if positive, indicates that the model is a better predictor than the average of measured values and results can be considered acceptable, Moriasi et al., 2007), the coefficient of residual mass (CRM, minimum = -∞, maximum = + ∞, optimum = 0, if positive indicates model underestimation and *vice versa*, Loague and Green, 1991) and the coefficient of determination ($R^2$, minimum = 0, optimum and maximum = 1). MAE and RRMSE measure the average difference between simulations and observations in the unit of the variable and in percentage, respectively; EF and $R^2$ describe the rate of variation explained by the model, thus stating the model capability to reproduce the trends of observed data along the 1:1 line; CRM quantify the tendency of the model to under- or overestimate the measured values.

A further model evaluation was performed via the Akaike Index (AIC, Information Criterion index, Akaike, 1973, the lower, the better), which is used to quantify the best trade-off between the accuracy of fit (explanatory power) and the complexity (number of variables and parameters).

**Simulations, data analysis and HRY forecast at provincial level**

After model calibration, multi-year simulations were performed in three municipalities (Castello d'Agogna, Vigevano and Giussago) in the period when reference data were available. Model outputs simulated at maturity stage were stored in the *Data analysis* layer (Figure 2) and aggregated, at provincial level according to the rice area in each municipality. The presence of outliers in the historical series of HRY was investigated via the non-parametric Hampel's test (Appendix D, Figure D2), since the assumption of normality was not satisfied (Davies and Gather, 1993). Normality test was carried out at 95% confidence interval through the Anderson-Darling (Anderson and Darling, 1952) and Shapiro-Wilk (Shapiro and Wilk, 1965) tests (Appendix D, Figure D1), the latter considered as very powerful with small samples sizes. The official statistics were analysed to identify any systematic time or technological trend via linear and quadratic regression. Results from outliers detection and trend analysis procedures are reported in the supplementary material (Appendix D, Figure D1, Tables D1 and D2).

In the *HRY forecasting* layer (Figure 2), multiple linear regression (MLR) models were developed using aggregated outputs at maturity stage as independent variables to explain the annual variability of provincial historical HRY data, in the period 1994-2013 for Loto and 1999-2013 for Gladio. The maximum number of model outputs (Table 1) included in the MLR was four. The top ten MLR models (i.e., those with the highest $R^2$ and root mean square error – RMSE, Fox, 1981) were selected. The risk of collinearity among predictors was checked via the Variance Inflating Factor (VIF) and the tolerance index (TOL). MLR models including collinear regressors were then excluded from the model selection for forecasting purposes. Values of VIF > 10 and tolerance index <0.01 were assumed as thresholds for high-collinearity (Belsey and Welsch, 1980). The remaining MLR models were tested via leave-one-out cross validation (LOOCV) using the RStudio package (Version 1.0.136 – © 2009-2016 RStudio, Inc). LOOCV is commonly used to quantify the reliability of a forecasting system in presence of limited data, by iteratively predicting each observation by means of all surrounding data as training set (Lessels and Bishop, 2015). The t-value was used to assess the statistical significance and the explanatory power of selected model regressors. The best MLR model after LOOCV was used to predict HRY in 2013 growing season, selected as the target year.

**Table 1:** Model outputs used as predictors to explain the annual variability of official head rice yield (HRY). * Development Stage Code: 1 = emergence, 2 = flowering, 2.5 = full ripening 3 = physiological maturity.

| **Predictors of the regression model** | **Acronym** | **Unit** |
|---|---|---|
| *Development* | | |
| DVS* | DVS | unitless |
| Cycle length | CYCLE | days |
| Length of the period from flowering to maturity | RIPE | days |
| *Grain quality* | | |
| Head Rice Yield | HRY | % |
| *Meteorological variables influencing the HRY* | | |
| 95-th percentiles of night-time air temperature | T95 | °C |
| Cumulative rainfall | RAIN | mm |
| Windy days during ripening phase | WIND | days |

### 6.1.3 Results

**Model validation at field level**

**Simulation of crop development**

Figure 3 reports the scatterplots between the observed and simulated day of the year of flowering and maturity of Loto and Gladio cultivars. Average errors in estimating flowering and maturity dates were four and ten days, respectively, with better results in calibration than in validation.

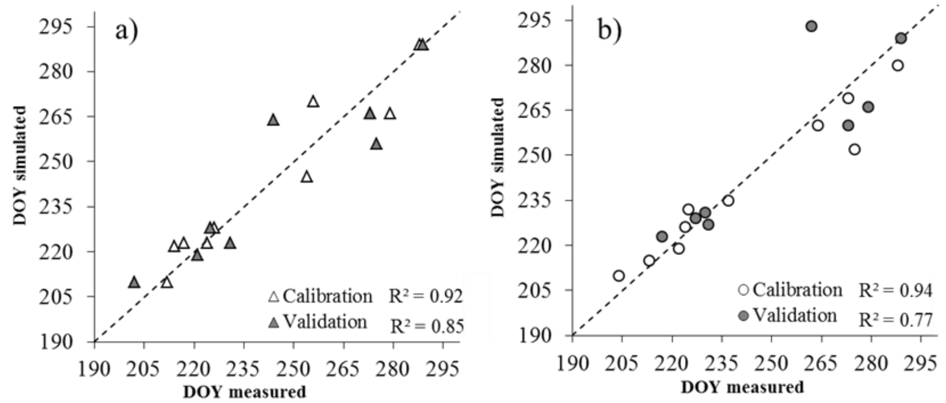


**Figure 3:** Comparison between measured and simulated phenological dates (a, b) for Loto (triangles) and Gladio (circles) rice cultivars in calibration and validation phase; the dashed lines represent the 1:1 line. DOY: Julian day of the year.

The model goodness of fit is confirmed by the values of the calibration and validation indices presented in Table 2, with MAE ranging from 3.25 days (Gladio, validation) to 5.25 days (Loto, validation) for flowering and from 8.2 days (Gladio, calibration) to 14.25 days (Gladio, validation) for physiological maturity. RRMSE values are in line with literature data (Confalonieri et al., 2009a) and ranged from 1.67% (Gladio, flowering, validation) to 6.54% (Gladio, maturity, validation); modelling efficiency was positive in all cases but one (Gladio, maturity, validation), and ranged from 0.28 (Loto, flowering, calibration) to 0.70 (Loto, flowering, validation). CRM values were very close to 0, denoting no systematic over/underestimation bias in the simulation of phenological development for the two cultivars.

**Table 2:** Indices of agreement between observed and simulated flowering and maturity dates for Loto and Gladio cultivars. C: calibration; V: validation; MAE: mean absolute error (days, d); RRMSE: relative root mean square error (%); EF: modelling efficiency (unitless); CRM: coefficient of residual mass (unitless); $R^2$: coefficient of determination (unitless).

| Cultivar | Phenological phase | Dataset | MAE (d) | RRMSE (%) | EF | CRM | $R^2$ |
|---|---|---|---|---|---|---|---|
| Loto | Flowering | C | 3.80 | 2.14 | 0.28 | -0.01 | 0.60 |
| | | V | 5.25 | 2.70 | 0.70 | 0.00 | 0.78 |
| | Maturity | C | 8.80 | 3.69 | 0.43 | 0.01 | 0.57 |
| | | V | 11.50 | 5.27 | 0.24 | 0.01 | 0.29 |
| Gladio | Flowering | C | 4.00 | 2.08 | 0.68 | -0.01 | 0.81 |
| | | V | 3.25 | 1.67 | 0.54 | -0.01 | 0.67 |
| | Maturity | C | 8.20 | 4.19 | 0.57 | 0.03 | 0.80 |
| | | V | 14.25 | 6.54 | -2.39 | 0.00 | 0.01 |

## Simulation of head rice yield

The comparison of the outputs of the two HRY models (Lanning et al., 2011 and the new model) with reference data is presented as scatterplot in Figure 4. Despite a good agreement in reproducing HRY for Gladio, the model by Lanning et al. (2011) did not succeed in reproducing the HRY variability for Loto (Figure 4a), with a marked overestimation at low values (below 58%).

The inclusion of the effects of rainfall and wind speed in the new model allowed to improve HRY estimates for Loto cultivar (average $R^2$ = 0.81, Figure 4c), whereas similar performances were obtained for Gladio (average $R^2$ = 0.93 for the new model, average $R^2$ = 0.82 for the model by Lanning et al., 2011).

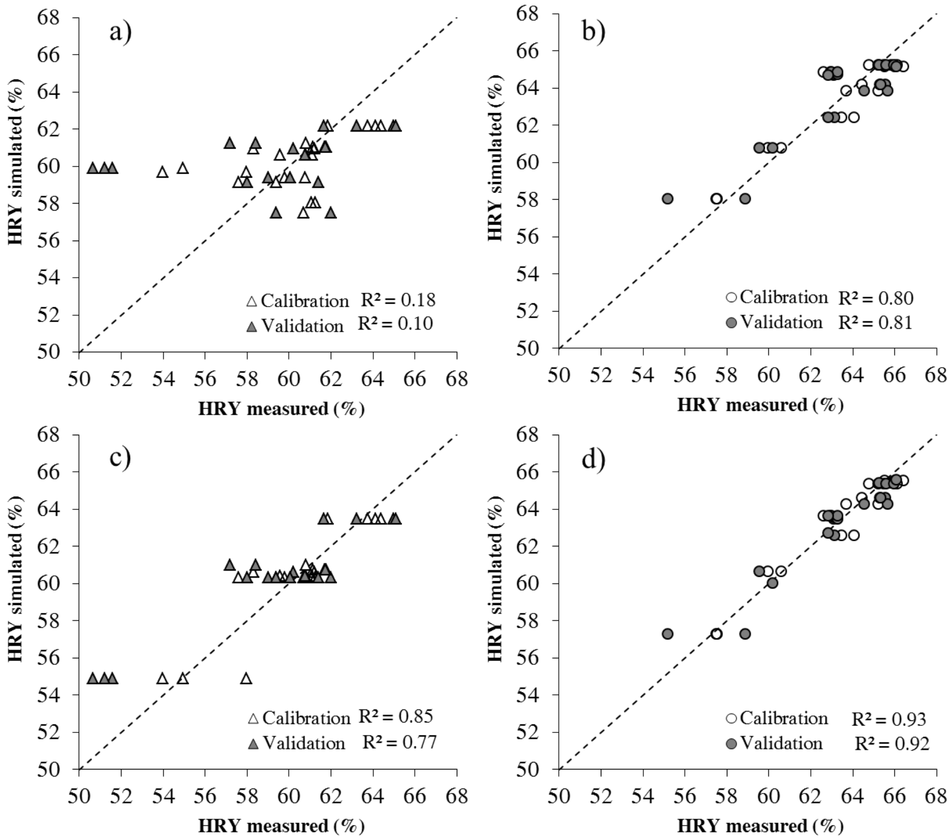


**Figure 4:** Comparison between measured and simulated head rice yield (HRY, %) values for Loto (triangles) and Gladio (circles) rice cultivars; simulations were carried out using the model by Lanning et al. (2015) (a, b) and the new model (c, d). The dashed lines represent the 1:1 line.

The values of the calibration and validation metrics presented in Table 3 confirmed the improved ability of the new model in reproducing the annual variability of HRY (average EF = 0.74), even increasing the accuracy in terms of average error (RRMSE = 2.79% for Loto; RRMSE = 1.18% for Gladio). The introduction of cultivar-specific coefficients in the new model led to average MAE = 0.6% (instead of 1%) for Gladio and average MAE = 1.32% (instead of 2.23%) for Loto. Regardless the statistical metric considered, the higher increase in accuracy was obtained for the *japonica* Loto, which is known to be more sensitive to temperature and humidity excursion in the post-flowering period.

**Table 3:** Indices of agreement between observed and simulated head rice yield (HRY) values, computed for Loto and Gladio cultivars. Performances of the original (Lanning et al., 2011) and of the new model were compared. C: calibration; V: validation; MAE: mean absolute error (%); RRMSE: relative root mean square error (%); EF: modelling efficiency (unitless); CRM: coefficient of residual mass (unitless); $R^2$: coefficient of determination (unitless).

| **Model** | **Dataset** | **Cultivar** | **MAE (%)** | **RRMSE (%)** | **EF** | **CRM** | **$R^2$** |
|---|---|---|---|---|---|---|---|
| Lanning | C | Loto | 1.76 | 3.88 | 0.18 | 0.00 | 0.19 |
| | V | | 2.69 | 6.57 | 0.05 | -0.02 | 0.11 |
| | *Mean* | | 2.23 | 5.23 | 0.12 | -0.01 | 0.15 |
| | C | Gladio | 0.94 | 1.78 | 0.81 | 0.00 | 0.81 |
| | V | | 1.03 | 1.99 | 0.80 | 0.00 | 0.81 |
| | *Mean* | | 0.99 | 1.89 | 0.81 | 0.00 | 0.81 |
| | *Total mean* | | 1.61 | 3.56 | 0.47 | -0.01 | 0.48 |
| New model | C | Loto | 0.96 | 2.07 | 0.77 | 0.00 | 0.77 |
| | V | | 1.68 | 3.50 | 0.73 | -0.01 | 0.86 |
| | *Mean* | | 1.32 | 2.79 | 0.75 | 0.00 | 0.81 |
| | C | Gladio | 0.56 | 1.05 | 0.93 | 0.00 | 0.93 |
| | V | | 0.64 | 1.31 | 0.91 | 0.00 | 0.92 |
| | *Mean* | | 0.60 | 1.18 | 0.92 | 0.00 | 0.93 |
| | *Total mean* | | 0.80 | 1.54 | 0.87 | 0.00 | 0.87 |

The AIC values obtained by the new model ranged between 6.09 for Gladio (original model = 10.25) to 34.99 for Loto (original model = 45.43), thus confirming the improvement of HRY simulations. For all the processes simulated and for both cultivars, calibrated parameters are presented in Appendix B, Table B.1 (development) and B.2 (HRY).

**GLORIFY performances at province level**

The performances of the top ten MLR models and the results of LOOCV are presented in Table 4.

The MLR models were more accurate in reproducing HRY variability in the whole historical series for Loto (average $R^2$=0.62) than for Gladio (average $R^2$=0.49). The MLR models including four indicators resulted as the most accurate in reproducing the variability of official HRY (average $R^2$ = 0.76 for Loto; $R^2$ = 0.56 for Gladio). These results were confirmed by the RMSE values, although differences between cultivars were smaller (average RMSE = 1.00% for Loto; average RMSE 1.19% for Gladio). As the models were tested with LOOCV, the average $R^2$ decreased up to 28% and 11% for Loto and Gladio, respectively. The $R^2$ values for Loto were higher than 0.40 in 50% of the cases, with highest value of 0.61, whereas the top ten MLR models for Gladio obtained worse performances (0.03≤$R^2$≤0.17), regardless the model indicators selected. RMSE values were in the range 1-2%, with the exception of model 4 for Gladio (RMSE = 2.30%).

**Table 4:** Results obtained by the best multiple linear regression model (MLR) to predict historical data of head rice yield (HRY). MLR: built using the whole HRY series; LOOCV: leave-one-out cross validation; RMSE: relative mean square error (%); $R^2$: coefficient of determination (unitless).

| # | Indicators | *MLR* RMSE (%) | $R^2$ | *LOOCV* RMSE (%) | $R^2$ |
|---|---|---|---|---|---|
| | | ***Loto cultivar*** | | | |
| 1 | HRY, T95, DVS, RAIN | 0.77 | 0.78 | 1.04 | 0.61 |
| 2 | HRY, T95, DVS, WIND | 0.82 | 0.75 | 1.19 | 0.48 |
| 3 | HRY, T95, DVS, CYCLE | 0.83 | 0.74 | 1.24 | 0.44 |
| 4 | HRY, T95, DVS, RIPE | 0.83 | 0.74 | 1.21 | 0.46 |
| 5 | HRY, T95, DVS | 0.84 | 0.73 | 1.13 | 0.53 |
| 6 | HRY, T95, RIPE | 1.06 | 0.58 | 1.62 | 0.13 |
| 7 | HRY, T95, CYCLE | 1.13 | 0.53 | 1.71 | 0.06 |
| 8 | HRY, DVS, CYCLE | 1.13 | 0.53 | 1.74 | 0.05 |
| 9 | HRY, DVS | 1.29 | 0.39 | 1.84 | 0.01 |
| 10 | DVS, RAIN | 1.30 | 0.38 | 1.74 | 0.07 |
| | | ***Gladio cultivar*** | | | |
| 1 | T95, CYCLE, RIPE, RAIN | 1.01 | 0.63 | 1.78 | 0.17 |
| 2 | HRY, T95, RAIN,WIND | 1.09 | 0.57 | 1.74 | 0.16 |
| 3 | HRY, T95, CYCLE,WIND | 1.14 | 0.53 | 1.93 | 0.09 |
| 4 | HRY, T95, DVS,WIND | 1.15 | 0.52 | 2.30 | 0.03 |
| 5 | HRY, T95, WIND | 1.15 | 0.52 | 1.74 | 0.14 |
| 6 | T95, CYCLE, WIND | 1.19 | 0.49 | 1.81 | 0.10 |
| 7 | T95, DVS, WIND | 1.22 | 0.46 | 1.68 | 0.14 |
| 8 | DVS, RIPE, WIND | 1.24 | 0.44 | 1.63 | 0.14 |
| 9 | T95, WIND | 1.31 | 0.38 | 1.68 | 0.10 |
| 10 | DVS, WIND | 1.35 | 0.34 | 1.70 | 0.08 |

The collinearity, the standard error (SE) and the statistical significance of crop indicators are presented in Table 5. The most frequently selected predictors for Loto were HRY and DVS, whereas for Gladio were the 95-th percentiles of night-time temperature frequencies (T95) and windy days (WIND) in post flowering, with average SE of about 0.2%, 1.5%, 0.3% and 0.15% respectively.

**Table 5:** Descriptive statistics from best combinations of model indicators against the official head rice yield (HRY) over the period 1994 - 2013 for Loto and Gladio. T-values (T) in light grey are significant at confidence interval of 95%. TOL: tolerance (unitless); VIF: Variance Inflating Factor (unitless); SE: standard error (%). Values in bold indicate collinear indicators (i.e., VIF > 10 and TOL <0.01; Belsey and Welsch, 1980).

| # | MODEL | TOL | VIF | SE | T | MODEL | TOL | VIF | SE | T |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Loto* | | | | | *Gladio* | | |
| | **HRY** | 0.41 | 2.47 | 0.17 | 4.86 | **T95** | 0.10 | 9.84 | 0.41 | -2.55 |
| **1** | **T95** | 0.14 | 7.07 | 0.24 | -4.49 | **CYCLE** | **0.02** | **51.00** | 0.12 | -2.91 |
| | **DVS** | 0.23 | 4.35 | 1.11 | 5.55 | **RIPE** | **0.03** | **32.72** | 0.13 | 2.85 |
| | **RAIN** | 0.84 | 1.19 | 0.01 | 1.63 | **RAIN** | 0.59 | 1.71 | 0.02 | -2.96 |
| **2** | **HRY** | 0.41 | 2.44 | 0.18 | 4.87 | **HRY** | 0.17 | 5.88 | 0.32 | 1.85 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **T95** | 0.14 | 7.00 | 0.26 | -4.53 | **T95** | 0.20 | 4.90 | 0.31 | -2.14 |
| | **DVS** | 0.17 | 5.80 | 1.37 | 4.80 | **RAIN** | 0.81 | 1.23 | 0.02 | -1.05 |
| | **WIND** | 0.47 | 2.12 | 0.10 | 0.81 | **WIND** | 0.55 | 1.82 | 0.15 | 2.40 |
| **3** | **HRY** | 0.41 | 2.43 | 0.18 | 4.75 | **HRY** | **0.09** | **11.15** | 0.46 | 0.86 |
| | **T95** | 0.10 | 9.85 | 0.31 | -3.45 | **T95** | 0.12 | 8.45 | 0.43 | -1.60 |
| | **DVS** | **0.09** | **11.19** | 1.94 | 3.45 | **CYCLE** | **0.05** | **18.82** | 0.08 | -0.43 |
| | **CYCLE** | **0.05** | **18.80** | 0.05 | 0.43 | **WIND** | 0.57 | 1.75 | 0.15 | 2.53 |
| **4** | **HRY** | 0.40 | 2.47 | 0.18 | 4.71 | **HRY** | 0.11 | 9.83 | 0.46 | 1.04 |
| | **T95** | 0.12 | 8.44 | 0.29 | -3.85 | **T95** | 0.22 | 4.58 | 0.32 | -1.79 |
| | **DVS** | **0.07** | **14.95** | 2.25 | 2.93 | **DVS** | 0.13 | 7.95 | 2.69 | 0.19 |
| | **RIPE** | **0.05** | **21.14** | 0.07 | 0.29 | **WIND** | 0.57 | 1.76 | 0.15 | 2.49 |
| **5** | **HRY** | 0.41 | 2.42 | 0.18 | 4.87 | **HRY** | 0.17 | 5.73 | 0.32 | 1.70 |
| | **T95** | 0.14 | 6.93 | 0.25 | -4.52 | **T95** | 0.23 | 4.34 | 0.30 | -1.89 |
| | **DVS** | 0.23 | 4.32 | 1.17 | 5.15 | **WIND** | 0.57 | 1.75 | 0.15 | 2.63 |
| **6** | **HRY** | 0.46 | 2.19 | 0.21 | 3.22 | **T95** | 0.12 | 8.43 | 0.43 | -1.67 |
| | **T95** | 0.12 | 8.42 | 0.35 | -3.01 | **CYCLE** | 0.10 | 9.68 | 0.06 | -1.46 |
| | **RIPE** | 0.16 | 6.11 | 0.05 | -3.30 | **WIND** | 0.67 | 1.50 | 0.14 | 2.41 |
| **7** | **HRY** | 0.45 | 2.23 | 0.23 | 2.99 | **T95** | 0.27 | 3.67 | 0.29 | -1.48 |
| | **T95** | 0.10 | 9.85 | 0.41 | -2.60 | **DVS** | 0.24 | 4.21 | 1.96 | 1.24 |
| | **CYCLE** | 0.14 | 7.26 | 0.04 | -2.78 | **WIND** | 0.71 | 1.41 | 0.14 | 2.25 |
| **8** | **HRY** | 0.59 | 1.69 | 0.20 | 2.60 | **DVS** | **0.06** | **17.30** | 4.07 | 1.26 |
| | **DVS** | **0.09** | **11.19** | 2.54 | 2.60 | **RIPE** | **0.06** | **18.17** | 0.11 | 1.30 |
| | **CYCLE** | **0.08** | **13.23** | 0.06 | 2.10 | **WIND** | 0.67 | 1.49 | 0.14 | 1.76 |
| **9** | **HRY** | 0.79 | 1.27 | 0.19 | 1.63 | **T95** | 0.81 | 1.23 | 0.17 | -0.78 |
| | **DVS** | 0.79 | 1.27 | 0.95 | 1.68 | **WIND** | 0.81 | 1.23 | 0.13 | 1.88 |
| **10** | **DVS** | 0.86 | 1.16 | 0.91 | 3.09 | **DVS** | 0.71 | 1.41 | 1.20 | 0.06 |
| | **RAIN** | 0.86 | 1.16 | 0.01 | 1.54 | **WIND** | 0.71 | 1.41 | 0.14 | 2.05 |

The average values of SE were always lower for Loto than for Gladio, the latter showing non-significant T-values in most cases (except for model 1 - all indicators were significant - and WIND, significant in 6 out of 9 cases). For both cultivars, indicators related to crop phenology showed severe collinearity in three cases out of ten (models 3, 4, 8 for Loto; models 1, 3, 8 for Gladio), with values of VIF and TOL that exceed their critical thresholds up to 5 times. The selection of highly collinear indicators negatively affected the accuracy of the MLR, as emerged by comparing model 4, including RIPE and DVS, and model 5, using only DVS, for Loto. Model 4 increased the explanatory power in MLR model building from 73% to 74%, but it markedly reduced $R^2$ from 0.53 to 0.46 in LOOCV (Table 4).

The same consideration is valid for model 5 and 3 for both cultivars, and for model 5 and 4 for Gladio. These models were excluded from the best model selection, and model 1 for Loto and 2 for Gladio were chosen to predict HRY in 2013 due to the highest $R^2$ values in LOOCV.

The ability of GLORIFY in reproducing official HRY statistics of Gladio and Loto are shown in Figure5.

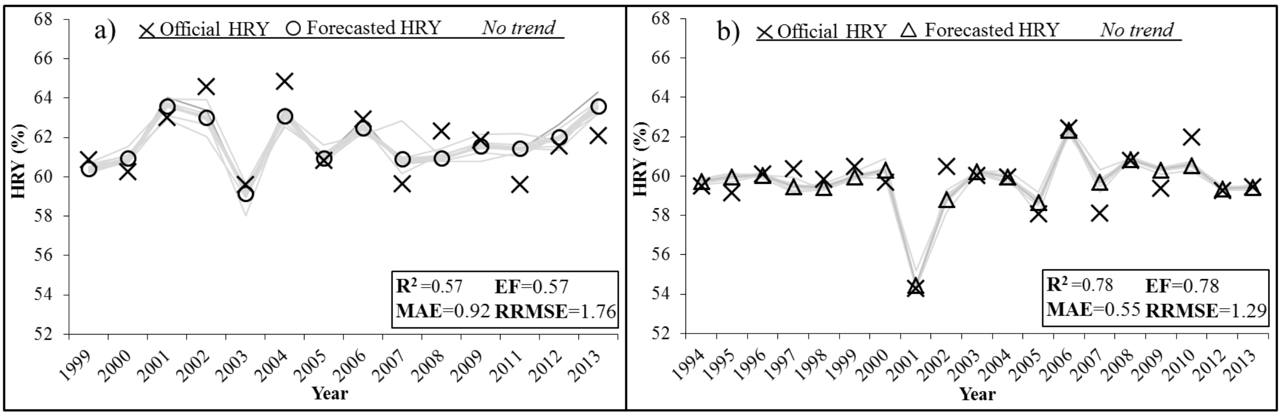


**Figure 5:** Comparison between reference and simulated HRY for Gladio (a) and Loto (b) at province level. $R^2$: determination coefficient (unitless); EF: modelling efficiency (unitless); MAE: mean absolute error (%); RRMSE: relative root mean square error (%). Light grey lines represent the outputs of the best model during leave-one-out cross validation.

GLORIFY performances in reproducing HRY were overall satisfactory, with better results for Loto ($R^2$ = 0.78) than for Gladio ($R^2$ = 0.57), and no trends in the historical series (Appendix D, Figure D2). For Loto, the MLR model succeeded in reproducing the year-to-year variability of official statistics (MAE=0.55%, RRMSE=1.29%, EF=0.78), and predicted HRY in the target year with deviations lower than 0.1%. The results for Gladio at province level were less accurate (MAE=0.92%, RRMSE=1.76%, EF=0.57), mainly due to low performances in the period 2002-2004 and 2007-2008. The tendency to overestimate HRY in the seasons 2011 (1.84 %) and 2012 (0.46 %), was confirmed in 2013 (target year), with an error of 1.5%. The best MLR model included HRY, T95 and RAIN (Table 4) for both cultivars, plus DVS for Loto and WIND for Gladio. T95, DVS and HRY were significant at 99% confidence interval for Loto, with HRY obtaining SE = 0.17%. Among the indicators selected for Gladio, similar accuracy was achieved by HRY (SE = 0.17%) and T95 (SE=0.20%), even though only WIND was significant at 95% confidence interval. Major differences between best model performances emerged when the outputs from LOOCV were represented (grey lines in Table 4); the low significance level of the indicators selected for Gladio was associated to a larger uncertainty in simulated HRY compared to Loto results (mean standard deviation, SD, of 0.28% instead of 0.11%), with the highest dispersion in 2002 (SD=0.41%) and 2007 (SD=0.58%).

### 6.1.4 Discussion

**Field scale**

The model parameters involved with phenological development and HRY were adjusted in calibration within the biophysical ranges of variations reported for Italian rice cultivars (Confalonieri et al., 2009b); all the other parameters were left to default values. Compared with previous studies (Confalonieri and Bocchi 2005; Confalonieri et al., 2009b), minimum and maximum temperatures thresholds for Loto development were lowered by 1 °C (10 °C versus 11 °C) and 2.5 °C (39.5 °C versus 42 °C), in agreement with Counce et al. (2000). These modifications were consistent with the lower thermal requirements of this *japonica* cultivar (Weng et al., 1987). The overall accuracy in simulating flowering dates laid the basis for a correct simulation of HRY, since the relevant model is grounded on crop phenology. The development of a new HRY model allowed to explicitly consider both the effects of meteorological conditions on the grain starch formation and deposition, and the cultivar-specific susceptibility to breakage, using parameters with a clear biological meaning (i.e., cardinal temperatures for starch formation). Indeed, suboptimal thermal and humidity regimes during ripening are the main responsible for the alteration of sink strength (Sreenivasulu et al., 2015), the incomplete seed filling (Ishimaru et al., 2009), the non-uniform moisture desorption from the grain surface before harvest (Lan et al., 1999), the increased night-time respiration rates (Sreenivasulu et al., 2015) and the degradation of starch due to α-amylase activity (Yamakawa et al., 2007). All these physiological processes contribute to the reduced biosynthesis and non-homogeneous packing patterns of starch granules in the caryopsis, which cause breakages during post-harvest processing.

In agreement with previous studies (Yoshida 1981; Chen et al., 2011), optimal temperatures for starch synthesis of the two cultivars were set in the range 25–27 °C, while the higher susceptibility to breakage of Loto grains was reproduced by increasing the slope of the temperature response function, by lowering the critical cumulative rain threshold (RainC = 14 mm instead of 7 mm) and by further reducing HRY under suboptimal conditions during early ripening (e = 5.4% instead of 1.7 %). The use of multi-year field experiments allowed to explore a wide variability of weather conditions characterizing the study area, thus increasing the reliability of model application. In 2005-2013, the 95 percentile of hourly temperature, windy days and cumulative precipitation in early ripening period were in the range 24.3 - 29.3 °C (mean = 26.7 °C, SD = ± 1.8 °C), 2.8 - 52 days (mean = 8.8 days, SD = ± 16.7 days), 0 - 148 mm (mean = 24.3 mm, SD = ± 48.51 mm). Major anomalies were observed in 2010, where the 56 % and 45 % of total windy and rainy days occurred. However, lowest HRY values were simulated in 2012 for both varieties, due to the joint effect of very dry (RainC < 1mm) and high windiness conditions (WindyD = 12 days, WindyTh = 10), coherently with observed values. The new model obtained better results than in previous studies carried out in the same area (Cappelli et al., 2014) and in the United States (Lanning et al., 2011). RRMSE, $R^2$ and MAE values were in line with literature values (RRMSE = 4 - 6.5 %; $R^2$ = 0.4 - 0.81; MAE =2 - 3 %), whereas average EF was considerably enhanced for both cultivars (EF = 0.92 versus 0.23 for *tropical japonica*; EF = 0.75 versus 0.29 for *japonica*). The modifications to the original model by Lanning et al. (2011) allowed to considerably improve HRY simulations especially for Loto cultivar, when small deviations from the optimum ranges of temperature and humidity occurred within the ripening period.

**Provincial scale**

The accuracy of GLORIFY was comparable to similar yield forecasting studies performed under a wide spectrum of agro-climatic conditions for sugarcane (Bezuidenhout and Singels, 2007b), wheat (El Jarroudy et al., 2012, Djaby et al., 2013; Kogan et al., 2013, Mavromatis 2014), maize (Mkhabela et al., 2005; Djaby et al., 2013; Wang et al., 2013) and rice (Manfron et al., 2013). At province/regional scale, these systems are usually able to explain about 55-60 % of inter-annual yields variability in the presence of technological and time trends, even reaching peak of 90-92 % when satellite-derived (de Wit et al., 2013) or simulated disease/water limited indicators (Pagani et al., 2013; Pagani et al, 2017) are included in the regression models. Available forecasting systems coupling process based and statistical models only focus on yield prediction (Mavromatis, 2007; Pagani et al, 2017). The only two studies available in literature focusing on qualitative aspects of crop productions addressed wheat protein content, respectively using a statistical (Lee et al., 2013) and a model-based (Toscano et al., 2014) approach. Best results were obtained by Toscano et al. (2014), who predicted wheat protein content in the major Italian supply basins with an average $R^2$ of 0.71. The goodness of that system was mainly due to the use of representative georeferenced data as input for simulations (e.g., measured grain protein concentrations, phenological, management, and soil data) and to the process-based approach used to simulate the sink driven transport of nitrogen to storage organs, as limited by nutrients and water availability. In Toscano et al. (2014), the use of reference data for nitrogen-limited productions further contributed to develop a simulation environment close to the real system, which allowed comparing aggregated outputs from model simulations with historical data, without the need of any statistical post-processing, using 8 years as reference period. Conversely, in our study water and nutrients dynamics in the soil-plant system were not simulated and statistical post-processing of model outputs was applied to further improve the performance of the forecasting system, also because our models did not consider the impact of nitrogen management on simulated yield levels. The historical HRY data used in the present study varied in the range 46.2– 62.5% for Loto (average 59.5%) and 59.6 – 71% for Gladio cultivars (average 62.5%) in 1994 - 2013 growing seasons, with no significant trend in time (Appendix D, Figure D2). The inter-annual variability of HRY was not correlated with seasonal weather trends ($0.05 < R^2 < 0.28$; F-values were not significant at any confidence interval; data not shown) and dynamic of harvest area ($R^2 = 0.05$) for Gladio, whereas a significant correlation with night-time temperature was observed for Loto at 95% confidence interval ($R^2 = 0.21$; Appendix C, Figure C1).

Nevertheless, GLORIFY was able to capture the variability of the official HRY ($0.34<R^2<0.78$), with results depending on cultivar and number/type of indicators selected. The application of LOOCV allowed to support model selection for forecasting purposes, minimizing the risk of overfitting despite the limited data availability. This procedure allowed to identify the MLR models which failed to reproduce HRY variability when iteratively tested against independent datasets generated via resampling techniques. The combined application of multicollinearity detection and LOOCV allowed to further refine best model selection, by excluding models with predictors that contributed to inflate model explanatory power.

At the end of the selection procedure, best results were obtained for Loto cultivar, as the regression model explained 78% of the HRY variability and matched HRY value in the target year. The indicators selected were significant at 99% confidence interval in three cases out of four, proving the accuracy of the model in seasons characterized by anomalous HRY values (i.e., 2001 and 2006). While suboptimal T95 temperatures in the ripening period and a high incidence of days with wind speed higher than the critical threshold in 2001 (-2.6 °C and + 40% compared to the mean of the period 1994-2013) decreased HRY values (54.3 %), the optimal weather conditions experienced by the crop in 2006 contributed to achieve a very high HRY (62.5 %). Conversely, HRY forecasts for Gladio presented a higher frequency of over and underestimation. Marked underestimations in 2002 (-1.6%) and 2004 (-1.8%) were related to the simulation of phenological development and associated uncertainties; indeed, the dry conditions in the early ripening stages decreased the rate of starch synthesis, despite of the large precipitation amount in these years (45 % of total amount in 1999-2013 period). The lack of consideration of yield-limiting factors in the simulation appears to be the main reason for the poor results in 2007 and 2011, when cold induced sterility and panicle blast infections during ripening (annual technical reports from ENR, http://www.enterisi.it/, and Regional Agency for Agricultural and Forest Services, http://www.ersaf.lombardia.it/) reduced Italian rice yields (Bregaglio et al., 2016) and grain quality.

**Perspective and limitations of the study**

The upscaling of model results from field to province level allowed collecting reliable information to feed the forecasting system with reduced uncertainty, but did not allow generalizing results to areas with different agro-climatic conditions or constraints to productivity. However, despite simulations were performed under non-limiting conditions for nutrients and water, GLORIFY could provide useful information even when applied in other Mediterranean areas where flooded rice production systems are present, as in Southern Spain (e.g., Aguilar and Borjas, 2005). Indeed, the HRY model accounts for site-specific meteorological data (e.g., hourly night-time temperature, daily precipitation and wind speed) and parameters (i.e., critical cumulative rainfall, wind speed and temperature thresholds triggering HRY reduction during the sensitive period after flowering) which allow modulating model responses according to the pedo-climatic conditions explored. In any case the application of GLORIFY in other areas should be preceded by a novel calibration of the rice simulator and of the HRY model in turns requiring reliable reference experimental datasets. The same consideration is valid, and even more important, when field-level model results are upscaled at regional level via multiple linear regression models. As a matter of fact, statistical models cannot be applied outside the conditions for which they are calibrated, due to their dependence on site specific factors determining their parameters values (Donatelli and Confalonieri 2011). In this context, indicators related to drought (RAIN) and temperature (T95) stresses are likely to show a higher explanatory power in warmer climatic conditions, compared to our results. Besides crop-specific susceptibility, indicators that are grounded on crop phenology are expected to play a key role even there, since the model responses are mediated by the time of occurrence of a drought or heat shock event/period.

Another limitation of the study relies on the application of the system to a limited number of cultivars. Our future perspective is thus to extend the application of GLORIFY to remaining Italian rice merceological groups (i.e., round and medium grain types) and/or sub-groups of varieties that share similar grain quality traits (e.g., long A grain types with high susceptibility to breakage). Although GLORIFY can already be adapted via parameterization to other cultivars, this objective is currently constrained by the lack of reference experimental datasets to evaluate model accuracy at field level. Our choice was then to focus on two main Italian rice varieties, Loto and Gladio, as representative of long A and long B grain types, together representing the 66 % of the Italian harvested area. In this perspective, also regression models should be re-calibrated using historical statistics to reproduce the sub-group specific traits and interannual trends of HRY.

A critical point in our approach is the formalization of the HRY model, which currently computes HRY only at rice maturity stage. Indeed, despite the model starts to assimilate daily and hourly meteorological data from flowering, the 95$^{th}$ percentile for night-time temperature used as input to estimate HRY is computed once maturity is reached. In the area rice maturity generally occurs in September/October, depending on the rice cultivar. Since the National Rice Authority usually provide preliminary estimates of seasonal HRY trends towards the end of the year, this means that GLORIFY allows the users to have access to timely information few months earlier than usual. Moreover, earlier forecasts could be performed if seasonal weather forecast is used. These data provide information about the expected state of the weather from 10-15 days to 3 months in advance, with increasing degree of uncertainty.

At last, the modularity and extensibility of the methodology developed foster its re-use in customized applications at an optimal resolution (e.g., field, district, regional, national) depending on the study purposes, on the resolution of available input data layers and/or on the homogeneity of pedo-climatic and farming conditions in the study area.

### 6.1.5 Conclusions

This study presents a new grain quality forecasting system for Northern Italy, which demonstrated to give reliable in-season estimates of HRY to be used by agricultural stakeholders at different levels, from farmers to regional politicians. Although GLORIFY accurately performed at field and province scale, it needs refinements to enhance precision at regional scale, especially for *tropical japonica* cultivars, which represent an increasing segment of Italian and European rice demand. Major improvements should involve the quality of input data and the model formalization, as the interactions between head rice yield and plant nutrients dynamics should be implemented. Furthermore, the GLORIFY system allows to be extended to forecast other qualitative variables influencing rice market prices.

**Acknowledgements**

This research received funding by the European Union Seventh Framework Program (FP7/2007-2013) under Grant Agreement 606983 (An Earth obseRvation Model based RicE information Service, ERMES; http://www.ermes-fp7space.eu/it/homepage/) and by Agropolis Fondation (through the "Investissements d'avenir" programme (ANR-10-LABX-0001-01)) and Fondazione Cariplo under the FIRST initiative (SCENArio integrated assessment for sustainable RICE production systems, ID SCENARICE 1201-008).

The rice icon in Figure 2 is created by Marco Galtarossa from the Noun Project.

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*Short Communication*

# 6.2 Networking, communicating and educating: the Opera18 experience for scaling up agroecology in Italy

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**Abstract**

This communication presents an overview of the genesis and the developing path of agroecology in Italy, which led the Project "Observatory for agroecology 2018" (Osservatorio per l'Agroecologia 2018 - Opera18). Opera 18 covered a crucial role in supporting and scaling up a broader understanding of agroecology among different stakeholders, i.e., researchers, farmers, advisors, park manager, environmental foundations, students, managers of food chains, mainly in Northern Italy. It was a pioneering project developed to connect different professionals embraced by agroecology and to promote, disseminate and recognise agroecological approaches and experiences. Opera18 consisted of one year ten free of charge classes open to participants with no barriers of age and affiliation. People involved were from different backgrounds and interacted discussing how to develop agroecological practices starting from the experience of 10 events. Opera18 was a horizontal transdisciplinary school of agroecology in which at the end all the actors will come out as multipliers of agroecological sustainable tools and practices that they could put in their agenda. Opera 18 set the foundation of the first Italian agroecological Association (AIDA) which aims to promote agroecology in Italy, developing a common national framework in connections with the European and Worldwide context.

**Keywords:** Scaling up Agroecology; Education; Networking; Transdisciplinary.

### 6.2.1 Introduction

Agroecology includes theoretical principles based on a systemic view and practical applications in agriculture towards sustainability [1].

The foundation of agroecology is close to agricultural sciences, but new dimensions of agroecology showed up, that is more concerned with promoting social transformations, rather than just with mere agricultural practices [2].

Agroecology is also a discipline that seeks to integrate science (e.g., agronomy, biology, sociology, history), practices and social aspects (e.g., local knowledge, active indigenous participation, food sovereignty) to guide research and actions towards a sustainable transformation of the current agri-food system [3, 4, 5]. This definition embodies a transdisciplinary-oriented approach, integrating knowledge from a broad range of disciplines [6, 7].

The concept of agroecology changed over the last 90 years. The scale of application changed from field level (from the 1930s to 1960s) to an agroecosystem level (1970s to 2000), and finally involving the whole food system [8].

Therefore, nowadays, the concept of agroecology is interpreted differently by stakeholders, depending on the emphasis given to the different functions of agriculture and its transformative potential. That statement underlines the potentially misleading use of the terms linked to the different approaches which are in one hand more radical and reformist and another weaker and elusive [2].

Someone considers agroecology only with a scientific or production-oriented approach, with a reductionist methodology which does not include social, cultural and political issues. This point of view neglects the aim of agroecology to criticise the current global agri-food system [9].

Therefore, there is a risk for agroecology for being co-opted, institutionalised, colonised and stripped of its socio-political content [10, 9].

In 2017 research-led in scientific databases analysed the development of the conceptualisation of agroecology in European Countries. The content analysis of a list of 574 documents from Scopus database considered that agroecology is a science followed by practice and to a lesser degree as a social movement [8]. This analysis showed that in the European context, research topics in agroecology not frequently regard new ways of relationship between society and agriculture. Currently, the European academic world is lacking in social, economic and cultural subjects about agroecology.

There is an ongoing discussion between the two ‘worlds’: in Europe, the scientific component of agroecology remains the dominant one, while in the Global South, practice and movements are historically the leading forces and are still mostly dominant [11].

This article presents an overview of the genesis and the development process of agroecology in Italy, where the origins of agroecology derive from the academic world. However, there are many movements, social initiatives and scientific studies that are very close to agroecological principles. Unfortunately, they do not use the term “agroecology” explicitly; thus, it is not easy to identify them and bring them closer to the academic world. In Italy, the constitution of an Observatory for Agroecology developed the Opera 18 project with the aims of disseminating agroecology and linking initiatives that already follow agroecological principles also with the academic world. Opera 18 involved different stakeholders in order to put the basis for Italian agroecology networks which considers together environmental, economic, social, cultural and political issues [12].

This project started from case studies and examples of best practices to support and scaled up a broader understanding of agroecology at the local level.

#### Agroecology in Italy

Agroecology in Italy developed between the end of the XIX century and the beginning of the XX thanks to agronomist and academic professors. They started to develop a systemic view of agriculture that would be strengthened in the second part of the XX century also thanks to environmental and social concerns provoked by the spread of industrial agriculture.

Pietro Cuppari (1816-1870) was a professor of agronomy in the University of Pisa (Italy) and first gave an essential contribution for developing the “organic theory” considering the farming system in terms of a living entity composed by climate, soil, crops, livestock, rural buildings, human resources and capital. The agronomist Alfonso Draghetti expanded the work of Cuppari in his book “Principles of farm physiology”. He considered the farms as a living system were the organs (e.g., all the parts of a farm) has a “physiology” provided by the farmers. The work of the farmer allows "circulation" and "re-cycling" according to the functional roles of the "organs" [1]. Another academic pioneer of agroecology was Girolamo Azzi (1885-1969), professor at Perugia University where he found the discipline of agricultural ecology. He proposed for the first time the analysis of the crop productivity based on the relationships between meteorology, crop' cycles and environmental features [13, 14] as a way to integrate separate sciences [15].

After the Second War World in Italy, the innovation strategy in agriculture started to follow the green revolution paradigm and promote a specialised, competitive and fragmented farm model neglecting agroecology research. The yield was only the result of genotype, and environmental interactions between crops and biotic and abiotic stress were limits that should be overcome by some products provided by the market and dependent on fossil energy (chemical fertilisers, pesticides, herbicides) [13].

From the '70s - '80s agroecological systemic approach was rediscovered and brought forward in agricultural research by Fabio Caporali (University of Tuscia, Viterbo) and Concetta Vazzana (University of Florence), both professors of agricultural ecology. From this generation, agroecology put the basis to include in the discipline also the social and economic dimension of agriculture and the different stages of food production, defined as "ecology of food systems" [6], when the most widespread agricultural model led to environmental and social concerns. However, in the mainstream view of national academies, agroecology was marginalised until the late 1990s, when the development of sustainable farming systems in Italy finally raised the interest of institutions. Nowadays, in addition to previous academic experience in the agroecological scenario [14], other Academies opened their classes using the term agroecology explicitly in the name of their courses. For example, the *Politecnico di Milano* in 2017 introduced the "Agronomy and agroecology", module in their teaching Ecology and Agronomic Science; An innovation was also introduced in 2019 by the University of Tuscia and the University of Turin together with a consortium of five French Agricultural Engineering High Schools (FESIA) and a Consortium of seven Scandinavian Universities (NOVA) which offered an MSc named Agroecology which is strictly connected with organic farming principles, theories and practices. The evaluation of the agroecological approach used in academic courses could be deepen in further studies.

In Italy, the development of agroecology is close to that of organic farming [14] which remains the main driver of agroecological research in that country [16]. For example, in 2017 the Italian Ministry of Agricultural, Food and Forestry Policies financed the transdisciplinary research project Risobiosystems which focused on participatory action research and organic farming which includes agroecological aspects in the Italian research scenery [17].

In Italy, organic farming started with farmers and consumer's demand. Before the first EU regulation on organic agriculture, some pioneers informally developed organic farming, starting from rejecting the industrial agriculture model. They refused to use artificial fertilisers and synthetic pesticides and were interested in preserving soil fertility, nutrient cycle, food quality, and health [18]. In the early eighties, consumers' movements and farmers' aggregations that promoted organic farming gave life to a commission to discuss the technical aspects of the organic method established the first nation-wide self-regulatory standards for organic farming.

Afterwards, organic farming practices formalised in a European regulation that leads to organic certification. Together with organic certification, other policies and certifications systems developed, for example, the biodynamic agriculture, integrated agriculture and geographical origin food product labels (Protected Designation of Origin, Protected Geographical Indication and Traditional Specialities Guaranteed) which aims to preserve local cultural food identities.

However, the organic certification system is not able to ensure that farmers follow fully agroecological approach. In some cases, the success and development of organic farming could make farmers downplay the fundamental role of agroecological principles and let them focus only on an input substitution approach, hence following the pathway of "conventionalisation" [14]. Mere strategies for replacing inputs with more socially accepted products (e.g. with an eco-friendly label) can have social consequences as they maintain the dependence of farmers with inputs purchased outside the farm [19, 20]. Towards this direction, agroecology also developed socio-economic principles such as social justice, food sovereignty and the preservation of cultural identities [21]. That it is crucial in order to develop sustainable agriculture beyond regulations and to involve all parties of the supply chain, from the producer to the consumer [18, 22], in Italy some initiatives were developed in order to amplify organic farming production together with the short supply chain. In 2015 the Italian Ministry of Agricultural, Food and Forestry Policies deployed the National Strategic Plan for the

Development of the Organic System. This act has the general objective to develop the organic system in Italy and aims to strengthen the production phase and vertical and horizontal connections of the supply chain. Toward this direction, there is the plan to increase the demand of organic products by the hospital and school canteens by promoting green public procurement which includes requirements of food from local and short supply chain [23, 24].

Even before, in 2004, in Italy, the first bio-district was born (Bio-distretto Cilento in Campania region), which is a portion of sub-regional territory lead by a no-profit association where the agroecological approach and methods of the organic production and consumption and agroecology followed together. The Biodistretto territorial structure involves farmers, citizens, local public administrations, and other stakeholders to develop sustainable farming practices in a participatory and win-win process. Afterwards, bio-districts have spread all over the country, and in 2014 the International Network of Eco-Regions (Bio-districts) was established in Rome [16].

Also, since late 1970s organic farming as well as many initiatives and movements dealing with food systems with participatory and inclusive approach have been raised in Italy. They follow agroecological principles and practices even though in many cases, they do not use the term "agroecology" [14] explicitly.

In Italy, example cases of associations and movement that are operative applications of some agroecological principles are the following. a) The international associations such as Slow Food that was born in Italy and safeguarded local food identities [25]. b) The association Italian Rural Seed Network (Rete Semi Rurali), which are dealing with agrobiodiversity protection, access and share to plant genetic resources and participatory breeding with the farmers [26]. c) The association Navdanya International, founded in Rome that operates all over the world for seed diversity conservation and food sovereignty and joins global campaigns in different countries [27].

In Italy, other initiatives that involve farms with an agroecological approach are alternative food networks, participatory guarantee systems [28] social farming and networks of the solidary economy [22]. There are many Italian NGOs and associations, e.g., Legambiente, Fondo Ambiente Italiano (FAI), Lega Italiana Protezione Uccelli (LIPU), Associazione Italiana Medici per l'Ambiente (ISDE), active in agri-food system innovation and advocacy for sustainability and agroecological transitions in Italy unified through the network Cambiamo Agricoltura [13]. It is certain that exist many more initiatives, networks, associations in Italy and Europe that deal with agroecology, but that do not use the term explicitly, and thus are not visible within this framework [11]. Therefore, there is a need for the mapping process and the recognition and evaluation of these initiatives.

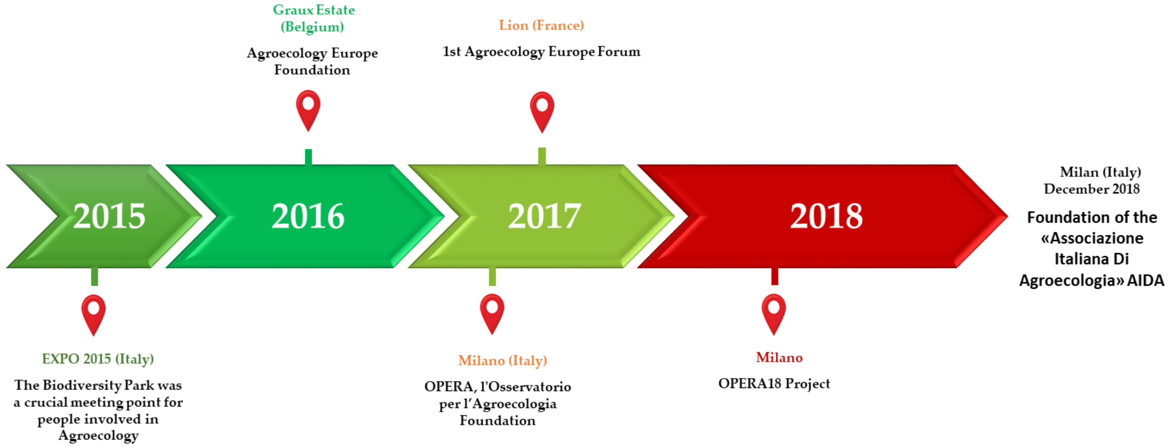
An essential event for the development of agroecology in Italy was the International Expo Milan 2015, Feeding the Planet, Energy for Life [14,16] where the Biodiversity Park Pavilion had a crucial role in disseminating and highlighting the aesthetical, cultural, socio-economic and environmental aspects concerned with agriculture to people, students, scientist, farmers and professionals more or less involved in sustainable agriculture.

The Joint Research Centre (JRC) of the European Commission, during Expo 2015, organised a conference which gathered several key persons who promoted agroecology in Europe and beyond, fostered the creation of Agroecology Europe. That is a European association established in January 2016, which aims to promote the agroecological transition in Europe and foster interactions across stakeholders and disciplines [14].

The birth of Agroecology Europe and the heritage of the International Exposition gave impetus to agroecology in Italy [14]. Advisors, researchers, farmers, policymakers, other relevant stakeholders involved in agroecology at different levels had the chance to meet at the Pavilion of Biodiversity at Expo 2015 in Milan. This experience represented the basis for the development of future discussions and processes on agroecology in Italy. In 2016, an informal group of people with different backgrounds created an informal and heterogeneous group of professionals which meets regularly, about once every two months, proceeding the process started during the Expo for scaling up agroecology, which flowed in the Observatory for agroecology (OPERA) founded in 2016. Initially, OPERA consisted of an informal group of people that gather together once every two months to discuss and debate about how to make a transition toward more sustainable and agroecological systems in the area of Milan. Members of OPERA were people involved in private and public entities like NGOs, universities, farms, associations (e.g., ACRA Foundation, University of Milan, Legambiente, Joint Research Centre Italia (JRC), Fondo Ambiente Italiano, International Society of Doctors for Environment), active in agri-food system innovation for sustainability and involved in the agroecological transitions through their work, mainly in Northern Italy. The attendance at the meeting was free, and people involved could open invitation to other colleagues to discuss new proposals for future actions, ideas, events share experiences and opinions. These meetings were the opportunities to make action plans and develop strategies for scaling up agroecology in the territory.

In 2018 from the basis of OPERA and the Opera 18 experience, a group of people founded the Italian Association of Agroecology (AIDA, Associazione Italiana di Agroecologia). That event connected for the first time individuals from academia, public and private NGO's, associations, professional studies involved in food systems with the aim of locally organise a network able to scale up agroecology in Europe and all over the world [13]. Figure 1 resumes the key steps that paved the way for AIDA foundation.

**Figure 1** This figure shows the key steps that paved the way for AIDA foundation in 2018 since Expo event in 2015.




**OPERA and Opera18**

As reported by [29], agroecology in Europe has challenges to overcome which fit into seven categories: 1) Definition and concepts; 2) Education and training, Knowledge sharing; 3) Research approach and funding; 4) Policies; 5) Productivity and practices; 6) Food systems and consumer's awareness; 7) Co-optation. During the analysis of these significant challenges for scaling up agroecology in Europe, carried out by 310 stakeholders in a World Café exercise and 23 sessions and workshops during the Agroecology Europe Forum 2017, some members of OPERA were present.

The Italian Observatory of Agroecology in agreement with the European challenges, have to face the great fragmentations of the Italian context and identified three main initial goals for agroecology in Italy:

1) Blurring barriers - Connect academic to movements and citizens.
2) Disseminating - Promote agroecology networking.
3) Creating a common framework - Develop agroecology with a territorial approach to overcome the fragmentation and heterogeneity of the different agroecological initiatives in Italy.

The first project written by members of OPERA was Opera 18, started in January 2018 and supported by Fondazione Cariplo, an Italian private foundation. Opera 18 aimed to promote and extend the network of OPERA' Observatory, increasing the number of members and categories of people involved, disseminating knowledge and at the same time stimulating the national discussion about agroecology. The project OperA18 provided the organisation of ten free-of-charge activities open to participants with no barriers of age and affiliation. The final goal was that agroecology reaches more people as possible, and these can start to follow agroecological principles in their professional activities. That work wants to communicate the experience that allowed members of OPERA to create connections between disciplines and stakeholders operating in the agri-food system and agroecological activities for scaling up and explain agroecology in Italy.

**6.2.2 Materials and Methods**

**Strategies for communication and sharing knowledge**

Opera18 consisted of a horizontal, transdisciplinary school of agroecology to communicate, sharing knowledge and networking. The value of the school is that all the actors involved in the school played an important role in sharing and promoting agroecological principles and practices. The activities also included relaxing moments such as offered light lunch, snacks or an appetiser, accompanied by music which meant for reflecting about the connections with the territory and the link between food, territory and people (e.g., ice-cream made with local farmer products). Also, the activities were in a way that active reflection and lively discussions with attendants took place. For this reason, experiential and action learning processes were used such as word café [30], Fishbowl [31], open discussions and learning-games guided by experts and key speakers were organised during the visits. The field visits focused on the principles of experiential learning [32], and the communication between participants was guided in order to allow the free flow of knowledge, ideas, feelings and awareness.

The approach of this school completely abandoned classical schemes of teaching, often based only on theory and made a step further on the field with practical experiences. The pedagogical principles of the school of agroecology supported the dialectical and horizontal relationship between educators and learners, with both teaching and learning in a constant dialogue free of hierarchy and dialogue among ways of knowledge between participants [33].

**The elements of Opera 18**

Opera18 considered that people involved in agroecology are developing practices and theories that could be useful to highlight the way to overcome challenges in different contexts if their knowledge and practices were applicable. Based on this, Opera18 created a School of Agroecology to exchange knowledge and to connect the following elements:

1) Pioneers - individuals belonging to different professional categories who were already involved in the agroecological discussion within the OPERA's members and followed agroecological principles in their activities.
2) Examples - private or public case studies which practically showed examples of agroecological best practices in the North of Italy. Each of them developed different aspects of agroecology.
3) Promoters - private or public stakeholders and individuals who are interested in agroecology and can contribute to sustaining agroecological principles after being in contact and "contaminated" by elements 1) and 2).

**The structure of Opera18**

*Table of pioneers* – Opera18 organised informal and heterogeneous group of professionals which met about once every two weeks, to discuss new proposals for future actions, ideas, share experiences and carry them into the Opera 18 project. This group included different categories of professionals, showed in table 1.

**Table 1** This table shows several categories and the number of pioneers which developed Opera18.

| **CATEGORIES OF PIONEERS** | **NUMBER OF PIONEERS** |
|---|---|
| Farmers | 2 |
| Members of Associations and Foundations | 6 |
| Policymakers and local administrators | 1 |
| Researchers | 5 |
| **All categories** | **14** |

The heterogeneity of members who can give a different point of view and the transdisciplinary approach characterised this group. Every member of the group involved other people interested in agroecology in participating as *promoters* in Opera 18.

*The class of promoters* - Opera18 in one year organised ten free of charge classes open to participants with no barriers of age and affiliation. They were involved by random dissemination of invitations by social networks, emails, and personal contacts of OPERA. The *promoters* were the School participants who are not called students because of their effective way of participating in the events and their future role in disseminating agroecology through their actions.

**School of Agroecology**

The "*School of agroecology*" is the tool for actively engaging and training *promoters* through on field visits to show *examples* and to reflect with each other. The visits of *examples* represented the starting point for discussions and reflections of the school. The table of *pioneers* performed the selection of examples which show different aspects of agroecology. For each visit at the *examples*, the number of attendants (*pioneers)* could be closed or open, depending on organisation variables such as space availability and funds.

Members of OPERA defined the case studies as *examples* for agroecology because of some aspects that they are facing or pursuing, but they were not yet officially agroecological. As we explained in the introduction in Italy, the movements and initiatives attributable to agroecology sometimes are not still defined as such, and it is necessary to map and evaluate them. The *examples* explored the SDGs themes of Agenda 2030 [34] and focused mainly on biodiversity, agricultural practices, food security, nutrition and health.

**Table 2** This table shows the *examples* with their characteristics and the number of *promoters* (attendants).

| EXAMPLES | COMMUNICATION AND SHARING KNOWLEDGE STRATEGY | SHORT DESCRIPTION | NUMBER OF PROMOTERS |
|---|---|---|---|
| *1, Presentation of pioneers* | Presentations and World Cafè | Multidisciplinary keynote speakers presented four main topics: seed sovereignty, food security, chemicals effects on health and agroecological practices. | 42 |
| *2,* Scientific project end meeting | Presentations, workshop, round tables, Fishbowl, field visit | Multidisciplinary speakers opened the discussion about digital innovation for sustainable agriculture and Food System | 79 |
| *3,* Mass public procurement visits | Presentations, workshop, round tables, field visit | Two case studies tour. In the morning, the visit to the mass catering of Milan (80000 meals per day) and Piacenza, an excellent example of how the mass catering can support local economies and communities. | 25 |
| *4,* Beekeeper farm | Presentations, documentary, field visit | A documentary shows about beehive bee breeding in an agroecological farm. | 50 |
| *5, Farmer market* | Field visit | Mill and farmer market visit as an example of local food-chain of bread from seed to farmers to consumers | 30 |
| *6,* Local food-chain *system* | Field visit | Tour in a mountain area to visit a local food chain for developing an abandoned area for the production of fodder at the base of the production chain of a rediscovered local cheese | 15 |

| | | | |
|---|---|---|---|
| *7,* Social inclusion projects | Presentations, round tables, field visit | Presentation of projects where immigrants were included in the society and empowered through food-related activities, e.g. catering, events, improve skills) | 35 |
| *8*, Open science meeting | Presentations, round tables | Presentation of research works related to organic agriculture in flooded rice fields listening directly to the stories of farmers involved in participatory research processes | 30 |
| *9*, Hospital and landowner | Presentations, round tables | Presentation of the projects for connecting local agriculture with the Hospital. Sustainable food functions as a source of therapy and prevention. | 30 |
| *10, Cereal-livestock Farm* | Presentations, round tables, field visit | Presentation of sustainable farming practices to increase soil fertility and biodiversity at farm and landscape level. | 30 |

**6.2.3 Results**

The Opera18 experience allowed to connect and include a broad range of people who had the opportunity to share and discuss agroecology and practical experience. The different topics of the ten visits as well as the diversity of locations and contexts, allowed to involve a considerable diversity of attendants into the school.

The school attendants were actively involved in the discussion to understand the transition process for scaling up agroecology and debates, which delivers direct output to people representing the *examples*. That reflects how every individual involved commits themselves to each other's learning, taking full advantage of the *example* available to harvest the most significant amount of education experience possible. The fact that *promoters* directly experienced the place of the visits allowed to make the learning process more concrete and practical than a classical and traditional lecture. Indeed, the approach of this school completely abandoned classical schemes of teaching, often based only on theory, and made a step further on the field with practical experiences.

Table 2 shows several *pioneers* who developed Opera18, and table 3 shows the number of *promoters* who attended at the school, both divided into professional's categories. The total number of *promoters* is ten times bigger than the number of *pioneers*. The most representative categories of *pioneers* were members of associations, foundations and researchers as in the categories of *promoters*. However, in table 3 of *promoters*, there are more categories than in table 1 of *pioneers*.

**Table 3** This table shows the number of promoters who attended the school, divided into professional's categories.

| **CATEGORIES OF PROMOTERS** | **NUMBER OF PROMOTERS** |
|---|---|
| Farmers | 10 |
| Food Chain Operators | 6 |
| Journalists | 7 |
| Members of Associations and Foundations | 52 |
| Policymakers and local administrators | 22 |
| Teachers | 2 |

| | |
|---|---|
| Researchers | 47 |
| **All categories** | **146** |

As a result, Opera 18 expanded the network, but some professional categories were less involved than others.

Table 4, summarised the categories of promoters less present and the main reasons because they have had problems in getting involved. We collected those reasons asking at the participants and using, e.g. emails, phone calls, messages with people who could not attend the events.

**Table 4** This table shows the categories of promoters who were less involved and the reasons for their low participation.

| CATEGORIES OF PROMOTERS | REASONS |
|---|---|
| Farmers | It was difficult to attend at events organised in the city also overlapping with the fieldwork schedule |
| Food Chain Operators and Journalists | It was necessary a strengthen dissemination campaign to engage professionals and associations of those categories' |
| Teachers | They need more targeted events and actions connected with the school's programs to involve students and teachers during school hours |

The most reached categories are policymakers and local administrators, member of associations and foundations and researchers. As a result, people involved, faced agroecology principles and practices personally and were motivated to put in their agenda what they learnt. For examples, policymakers were likely encouraged to include agroecological principles in the policy decision process, students and professors in their researches, NGOs in their projects.

### 6.2.4 Discussion and conclusions

Opera 18 experience was the first project developed in Italy to connect different agroecological professionals and to promote and disseminate agroecology. This project involved some categories of professionals successfully but had some difficulty with others. This point is crucial for future projects for examples organising events more in the countryside to reach farmers and actions more connected with schools' schedule for the teachers.

That experience proposes a replicable methodology and structure to involve actors and disseminate agroecology in other European contexts which are trying to scale up agroecology in their country. The OPERA's members and the promoters who joined Opera 18 project set the foundation of the first Italian agroecological Association (AIDA) in December 2018. This association aims to promote agroecology in Italy, developing a common national framework in connections with the European context.

It is clear that the path is still long and needed a reliable and shared effort in the next future. A priority is to link the different agroecological initiatives in Italy and broad the number and spectrum of people involved. The principal aim is combining and bonding together all the different involved realities – agriculture, socio-economic entities, policy and decision-makers, various stakeholders - setting transdisciplinary as a value in a systemic vision of agroecology – as a unique strategy to conjugate together academic theories and practitioners. In July 2019 AIDA started the new project Opera19 supported by the Italian foundation Fondazione Cariplo for one year and a half. Thanks to the experience of Opera18 and the actual need for concrete action for support agroecology [34], the next steps will allow a mapping process and the developing guidelines for agroecology in Italy.

**Author Contributions:** Conceptualisation, methodology, investigation, resources, data curation and writing—original draft preparation, Tommaso Gaifami and Valentina Vaglia; writing—review and editing and methodology, Camilla Zoppolato.; methodology, visualisation and validation, Ambrogio Zanzi; methodology and review, Francesca Orlando; review supervision and funding acquisition, Stefano Bocchi. All authors have read and agreed to the published version of the manuscript.

**Funding:** Fondazione Cariplo funded Opera18 with a grant of 70.000 euros.

**Acknowledgments:** OPERA'S and AIDA'S members and founders: Salvatore Basile, Paolo Bàrberi, Marco Bertaglia, Gianluca Brunori, Rosalia Caimo Duc, Fabio Caporali, Giuseppe De Santis, Damiano Di Simine, Fausto Gusmeroli, Arturo Lanzani, Antonio Longo, Renata Lovati, Giorgio Menchini, Carlo Modonesi, Nicola Morganti, Elena Muscarella, Fausto Moretti, Dario Olivero, Cesare Pacini, Marco Pezzetta, Costanza Pratesi, Niccolò Reverdini, Roberto Spigarolo, Concetta Vazzana.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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## 6.3 Planetary Health Alliance annual conference

**Contribution type:** Poster - Stanford University, 04/09/2019-07/09/2019

**Authors:** Zanzi A., Bocchi S.

**Title:** From local ecological restoration to planetary health: how urban agriculture can assure sustainability to our growing urban environments

In the recent decades, a rapid urbanization is taking place, bringing expanding cities and farming systems in closer proximity: today the majority of the population lives in cities, which use the 75% of natural resources, occupying just the 2% of Earth's surface. This phenomenon is resulting in a degradation of natural resources and in an irreversible loss of ecosystems. It appears thus clear the need of finding new strategies to assure urban sustainability: whether in terms of food, energy or soil, abundance can no longer be taken for granted in metropolitan areas. Starting from these assumptions, the European Union has recently funded "OpenAgri", a project aimed at the creation of an innovation centre in Milan, focused on urban agriculture, offering new responses to the sustainability challenges in Milan area, which today faces particular issues - from soil consumption to an increasing youth unemployment rate. Therefore, OpenAgri acts on different levels: on the social hand, with the motto "new skills for new jobs", it aims at creating an agri-food hub, with new start-ups providing food to the local market; on the other hand, the restoration of currently abandoned areas, preserving soils and promoting agricultural environments. Involving local farmers, citizens, municipalities and European decision-makers with a bottom-up approach, OpenAgri is a first answer to a double socio-environmental challenge, combining together different, but linked aspects: socio-economic benefits, food production and environmental preservation, which, in the project, is estimated thanks to the Biological Territorial Capacity (BTC), a fundamental landscape bionomics index, capable to assess the balance and the quality of a given environment, by measuring the degree of the metabolic capacity of vegetation communities. First results show BTC improvements – thus proofing project goodness and its positive impact on local environmental health, and, if scaling up project approach in multiple cities globally, on planetary health.

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Title: From local ecological restoration to planetary health: how urban agriculture can assure sustainability to our growing urban environments

# Growing cities, Urban Agriculture & SDG goals

In recent decades, we have witnessed **significant socio-economics changes**, with a major impact on urban environment:

- An uncontrolled **migration from rural area**: more than half of World's population live in cities, compared to 13% in 1900
- Urban areas use the 75% of natural resources, even if they occupy only the 2% of Earth's surface (FAO,2016)
- An increased in extreme weather events, with higher temperature and greenhouse gas emissions;

In this context, UN adopted **Agenda 2030**, defining 17 Sustainable Developments Goals (SDGs), to be reached within 15 years. Urban Agriculture can help in:

- Meeting **15 SDGs goals**
- Providing several **Ecosystem Services (ES)**
- Linking landscape areas, such as rural-urban areas

However, today Urban Agriculture has to deal with:

- **Underestimation** by decision-makers
- Lack of **budgetary** resources
- Technical **errors in planning and management phases**, since the urban tree lifespan is too limited

**It appears thus urgent to change the way we plan urban environment, to improve its sustainability**

# UIA OpenAgri: Aims and location

Following this need, the EU founded "**OpenAgri**", with the aim of creating an innovation center focused on peri-urban agriculture and agri-food chain. OpenAgri aims to connect **four dimensions**:

i) **sustainability** in food production; ii) **system innovation**, by fostering a hub for agri-startups; iii) the creation of **new jobs**; iv) **multidisciplinarity**, since it reconciles production and agroecology, with the implementation of 5 ha in **hedges and rows**.

The project area is located in the peri-urban area of **Nosedo**, a historical landscape, once the agricultural hearth of Milan thanks to the "*marcite*" meadows systems, today with a need of requalifications.

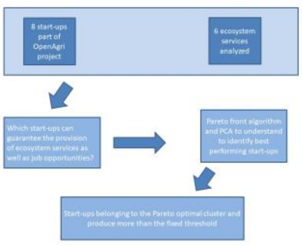
# Agroecological requalification

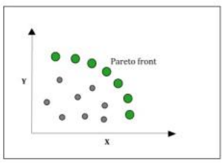

The requalification of the 35 ha area is following principles of sustainability, giving priority to agroecological practices. We selected 8 agri-food start-ups that will work on the project area, mainly cultivating for the local urban market and we have developed the **first expert system** capable to self-assess the energetic consumption of an urban farm, to let the start-ups know their energetic footprint.

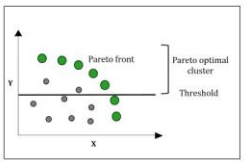
# Trade-Off analysis and ecosystem services quantification

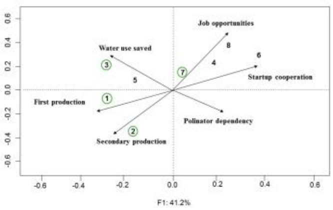
We are analyzing the provision of ES granted by each start-up for the following ES: primary and secondary production; crop pollination dependency; water used saved; job opportunities and start-up cooperation. Since in Milan the socio-economic conditions are worsening – high youth unemployment rate (28,6 %), percentage of NEETs at 17,6 % - we decided to investigate the link between provisioning of ES and creation of job opportunities granted by the 8 start-ups.

We used the Pareto frontiers algorithm to highlight ES trade-offs and to show which start-up was able to enhance ES and incomes simultaneously. A threshold was taken into consideration, corresponding to the last three years average monetary value production of all the farms in Regione Lombardia, which amounts to 108823,00 €/year. To better explore the results of the Pareto front algorithm a Principal Component Analysis (PCA) was performed.




From our results it is clear that some start-ups represent are capable to combine the provision of multiple ES as well as economic incomes. To us, this is possible because of several aspects common to each different start-up: first of all, a multidisplinary approach which takes into consideration solid business plan, rational use of resources and adaptability to the changing urban market.

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### 6.4 FAO World Forum on Urban Forests

**Contribution type:** Poster - Mantova 28/11/2018-01/12/2018

**Authors: Zanzi A., Ingegnoli V., Bocchi S.**

**Title: Landscape bionomics and urban forestry: a paradigm shifts to make our cities sustainable**

The importance of urban forests has been greatly underlined in the last years: if properly managed, they play a central role to improve the quality of life and meet the challenges set by Agenda 2030, helping to reach 15 Sustainable Development Goals (SDG), providing ecosystem services and making our cities safer, healthier and wealthier. However, although this relevance, urban forestry has to deal with at least two main issues: i) lack of budget, that often decision-makers address to other priorities; ii) problems in planning and management phases where a systemic approach is not always followed, even if it should be a priority to maximize the provided ecosystem services and the contribution to SDG achievement. As a result, today the role of urban forests is still too limited, without long-term impact. Therefore, it seems urgent to consider urban forests in their whole ecological context as a complex system, as theorized by landscape bionomics, analysing each biological link between the several entities involved in providing ecosystem services. Moreover, a major goal to make urban settlement sustainable should be the increase of the Biological Territorial Capacity (BTC), which is considered as the main ecological parameter in landscape bionomics, since it can precisely assess the balance and the quality of a given environment. In this field, the application of the BTC is still at a starting point, but it can be crucial to evaluate the ecological effects linked to different planning scenarios, thus being a useful instrument for landscapers and decision-makers. A first application is now ongoing thanks to the Urban Innovative Action project “OpenAgri” - which is aimed at retraining a 35 hectares peri-urban area in Milan - by simulating several planning options and choosing the one which assures the highest BTC value, so giving the city a future ecological high-performing urban forest.

World Forum on Urban Forests
Mantova 2018

Session:
The future
Day:
30th November

Speakers name:
Stefano Bocchi, Ambrogio Zanzi, Roberto Spigarolo, Vittorio Ingegnoli
Institution /University:
University of Milan

Title:
Landscape bionomics and urban forestry
a paradigm shift to make our cities sustainable: the OpenAgri case of study

UNIVERSITÀ DEGLI STUDI DI MILANO

# Urban Forestry, Urban Agriculture & SDG goals

In recent decades, we have witnessed **significant socio-economics changes**, with a major impact on urban environment:

- An uncontrolled **migration from rural area**: more than half of World's population live in cities, compared to 13% in 1900
- Urban areas use the 75% of natural resources, even if they occupy only the 2% of Earth's surface (FAO,2016)
- An increased in extreme weather events, with higher temperature and greenhouse gas emissions;

In this context, UN adopted **Agenda 2030**, defining 17 Sustainable Developments Goals (SDGs), to be reached within 15 years. Urban Forestry can help in:

- Meeting **15 SDGs goals**
- Providing several **Ecosystem Services (ES)**
- Linking landscape areas, such as rural-urban areas

However, today Urban Forests have to deal with:

- **Underestimation** by decision-makers
- Lack of **budgetary** resources
- Technical **errors in planning and management phases**, since the urban tree lifespan is too limited

**It appears thus urgent to change the way we plan urban environment, to improve its sustainability**

# UIA OpenAgri: Aims and location

Following this need, the EU founded "**OpenAgri**", with the aim of creating an innovation center focused on peri-urban agriculture and agri-food chain. OpenAgri aims to connect **four dimensions**:

i) **sustainability** in food production; ii) **system innovation**, by fostering a hub for agri-startups; iii) the creation of **new jobs**;

iv) **multidisciplinarity**, since it councils production and agroecology, with the implementation of 5 ha in **hedges and rows**.

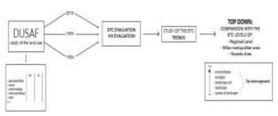
The project area is located in the peri-urban area of **Nosedo**, a historical landscape, once the agricultural hearth of Milan thanks to the "*marcite*" meadows systems, today with a need of requalifications.

# Landscape Bionomics principles


The ecological requalification of the 35 ha area is should follow some **Landscape Bionomics** (LB) principles. LB recognizes that Life on Earth is hierarchically organized in complex systems, acting as living entities. Among the most important functions of LB are **Human Habitat (HH)**, definable as the area influenced by man, and BTC – **Bionomics Territorial Capacity of vegetation** – that measures the degree of the relative metabolic capacity of vegetation communities in Mcal/m$^2$/year.

# Landscape Bionomics analysis and perspectives

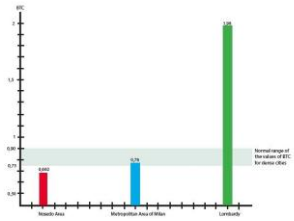
The LB concepts were applied to the Landscape Unit of Milano Chiaravalle – 1934 ha, including OpenAgri – to **understand the trend of HH and BTC in the last 60 years**. The needed information were elaborated from DUSAF Regione Lombardia:

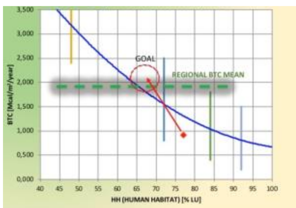




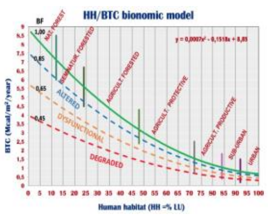
Landuse categories in the years.

Looking at soil destinations in 1954, 1999 and 2015, it is clear the reduction of arable land, in favor of urbanization.
This has led a **decrease in BTC value**, even lower than in Milan Metropolitan Area. By fostering a bionomics requalification, we aim to **increase the BTC value**, at least to reach the regional level, mainly **thanks to green corridors and a wise planning with wooden patches, hedges and rows, in connection to farming and cropping system, and agroecological management.**






The Recovery Design must be conducted following Bionomics Diagnosis and controlling the Goal. Note that a **Park must be above the mean BTC of the region** (left image). LB is able to control the design scenarios. The HH/BTC model, able to measure the bionomics state of a LU. In the right image, dotted lines express the BF level, that is the bionomics functionality of the surveyed Landscape Units (LU).

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### 6.5 2nd Agroecology Europe Forum

**Contribution type:** Poster - Technological Educational Institute of Crete, 26/09/2019-28/09/2019

**Authors:** Zanzi A., Bocchi S.

**Title:** Assessing the role of agroecology in the environmental and socio-economic redefinition of urban areas: the OpenAgri project

The importance of urban agriculture has been greatly underlined in the last years: if properly managed, it could play a central role to improve the quality of life and meet the challenges set by Agenda 2030, helping to reach 15 Sustainable Development Goals (SDG), providing food, as well as ecosystem services, thus making our cities safer, healthier and wealthier.

However, although this relevance, urban agriculture has to deal with at least two main issues: i) lack of budget, that often decision-makers address to other priorities; ii) problems in planning and management phases where a systemic approach is not always followed, even if it should be a priority to maximize the provided ecosystem services and the contribution to SDG achievement. As a result, today the role of urban agriculture is still too limited, without long-term impacts and an overall strategy. Therefore, it seems urgent

the need of building new examples of urban food systems, taking into consideration the growing urbanization and all the related phenomena. The creation of local food systems in our cities can lead to a more equal and right food access; an increase in food quality; a restoration of abandoned lands and in an overall socio-economic improvement.

Starting from these assumptions, the Urban Innovative Action Initiative has recently funded "OpenAgri", a first project aimed at the creation of an innovation centre dedicated to urban agriculture, with the aim of improving the food system and its sustainability in the metropolitan area of Milan.

Moreover, Milan is today facing huge social changes, with the youth unemployment rate at 28,6% and the percentage of NEETs at 17,6%. Thus, OpenAgri aims at acting on different levels: on the social hand, with the motto "new skills for new jobs" the project aims at creating an hub open to start-ups focused on agri-food technologies, hence giving to youngster and NEET chances of employment; meanwhile, on the other hand, the project assures the restoration of abandoned areas and the conservation of agricultural environment: a first answer to the double social-environment challenge, which in the future will characterize even more urban environments.

In the ongoing project, University of Milan is in charge for developing the agricultural restoration of the area: following an agro-ecological approach, in the 35 ha area, we plan to rebuild the link between city and countryside thanks to hedges and rows, having an improvement of Biological Territorial Capacity (BTC), which is considered as the main ecological parameter in landscape bionomics, since it can precisely assess the balance and the quality of a given environment, measured in degree of the relative metabolic capacity of vegetation communities in Mcal/m$^2$/year.

First results show an increase of BTC values – from the actual one (0.62) to a level above the urban average (0.75-0-90) – thus making OpenAgri a concrete example of agro-ecological transformation in the hearth of a growing city, balancing both socio-economic interest both food and environmental needs.

### 6.6 Planetary Health Alliance annual conference

**Contribution type:** Poster – April 2021

**Authors:** Zanzi A., Ante Testard P.A., Palmer K., Yglesias M.

**Title:** PlaHNet: Building a young professional community to spread Planetary Health awareness

The concept of Planetary Health is still at a starting point, especially outside of the academic world. For this reason, attempts to raise the attention of the public should be encouraged. Following these needs, at the beginning of 2020, a network of young professionals and students founded PlaHNet, a non-profit organization that envisions getting youngsters involved in Planetary Health through education, advocacy, creativity and collaboration. PlaHNet is focused on the dissemination of the Planetary Health concept, with the main goal of increasing awareness and putting into practice its principles, thus representing one of the first endeavours to actively involve young people in Planetary Health. Despite COVID-19 limitations, the association has seen growth and development, hosting a wide range of activities, such as: free webinars with prominent experts in the field of Planetary and Environmental Health; Photo Advocacy Contest for Nature, to depict environmental changes during the lockdown; and a Medium account for members to express themselves through blogging about Planetary Health and/or COVID-19. Through these blogs, we have also contributed to the COVID-19 Resource Pack hosted by the Northern Europe Regional Hub and Students for Planetary Health. Moreover, during 2020, PlaHNet welcomed new additions to the Leadership Board and created an independent Advisory Board, composed by 7 recognized experts, to mentor the association. These activities resulted in an increase of active members, now 30 from 17 countries. Furthermore, PlaHNet has achieved recognition from the PHA as an official member. This has prompted new goals and opportunities for the association: namely, to become established and distinguished promoters of several initiatives. Thanks to closer collaboration with other PHA members, we can create long-lasting collaborations in active research in the multiple fields of PHA, and in spreading Planetary Health concept to young professionals, to help pave the way towards a sustainable future.

## Conclusions and perspectives

Regarding the fundamental questions addressed during the dissertation and Ph.D. period – the understanding of ES concept variation in different environments, and secondary, how to integrate and council human development and ES improvements – the dissertation, thanks to the analysis of different case studies, has revealed that, adapting the usual perspective, is possible to increase ES levels, while continuing to assure traditional functions. Nevertheless, what emerges through the case studies is that the type of ES provided and the provision level greatly change, depending on environmental conditions and contexts. More specifically, the adoption of sustainable agriculture techniques leads to the improvement of supporting and regulating ES, with particular reference to soil and water properties, due to chemical input reduction. However, further researches should be carried out, to assess possible EDS and to find the right balance between food production and other ES. Anyhow, it is stated the agriculture should abandon a mono-dimensional approach, to evolve in a multidisciplinary one, capable to assure different economic sources to farmers too.

Moreover, in the assessment of agroecology and agroforestry systems, it would be interesting to further evaluate which are the best territorial configurations that optimize ES and farmers interests. Lately, new and still to be studied approaches has arisen in the international panorama, such as syntropic farming, whose application still need to be verified out of tropical climate zone.

A deeper approach is also needed regarding the sustainability evaluation presented in Chapter 4. Indeed, even if the topic is on the rise and becoming more and more actual, a compared study between different frameworks may underline strengths and weakness of each one, thus enabling a more aware choice during sustainability assessment.

At urban level, the case study presented in Chapter 5 demonstrates the high complexity of this type of environment. Even on a limited spatial scale, the involvement of multiple stake-holders and the high interest of citizens make it complex to sustain building projects and the safeguard of green spaces. However, both European and National regulations put effort in the direction of protecting urban natural capital: these legislative attempts, however, still need to be acknowledged by local stake-holders, and in particular by the ones who regulate and propose territorial planning (e.g., municipalities, planners and construction companies). Without a sharper action in involving these parts, the implementation of firmer regulations may result as incomplete in the practice. In this view, the methodology presented and applied to the Milan urban park – that still need a wider and vertical study – may later represent an ideal methodology to be adopted in similar requalification projects to help municipalities to deal with the need of natural capital preservation.

With the respect of the various activity presented in Chapter 6, it is interesting to note the wide approach maintained during the three-year period. The opportunity to work on new concepts, such as Planetary Health, and affirmed techniques, such as models, has greatly expanded the horizon of the Ph.D. and the future perspectives.

In general terms, one of the main aims of the dissertation was to provide a critical picture of the state-of-art of the ongoing panorama in ES provision, with the goal of identifying the most strategic research directions and practical trends to be later investigated. In this view, the dissertation and the doctoral activity have represented a crucial foundation, since they allowed to identify and define further steps to be investigated. In addition, the research activity has revealed that multiple tools and frameworks are available on the panorama, however the choice – and the needed calibration to each environment – is subjective and depends on researcher's point of view: therefore, the methodological choice should be done only after and in-depth analysis of specific scenario and available framework, and constantly updated.

Moreover, thanks to the lens of a combined theoretical approach and the assessment of practical case studies, the dissertation has confirmed that, following a double path of investigation – mixing together academic and applied research –, it could be possible to better integrate ES provision in each of the analysed topic, as agriculture, territorial planning and urban requalification.

In particular, the following points were identified to be further investigated:

- First, on an academic point, the most interesting topic that should be in-depth studied is the complex and dynamic relation between Ecosystem Service and Ecosystem Disservices due to agricultural activities. Indeed, till today, several researches assessed ES provision from different agricultural systems, but few studies investigated correspondent EDS levels. In particular, the topic could be addressed to the investigation of the so-called new forms of agriculture – such as, agroecology and agroforestry – to better analyse pros and cons of their adoption on a larger spatial scale.

- Regarding urban environment, the major trend identified regards the definition and proposal of a more structured methodology to be adopted within urban planning activities, to both conserve and improve urban natural capital role. In this term, new areas have been identified where to calibrate and validate the methodology presented in Chapter 5.
  In this field, another interesting topic to be studied is the development of a PES-like scheme, linking the implementation and conservation of urban green areas to economic incentives.

- Finally, the need for ES quantification has led to the adoption of models and scientific tools, which often need more accurate activities of calibration, validation and adaptation to different environments. Today, the actual and future role of technological and digital tools in improving ES level is undeniable. In the next future, a broader integration between public policies and technological instruments will become even more solid: therefore, a stimulating research branch is represented by implementing scientific instruments (e.g., remote sensing) in rising subject, such as urban forestry.

In the light of these scenarios, future researches should be focused not on Nature Based Solutions approach, but primarily on Ecosystem Based Solution, thus favouring the provision of ES minimising EDS.

A long path that has just started!

*Ad maiora!*