Leaves © ICLEI

# Living Labs impact at the NBS level

## Deliverable 4.9

Work package: 4

Dissemination level: PU

Lead partner: CNR

Author: Chiara Baldacchini

Due date: 30/11/2023

Submission date: 29/11/2023

| | |
|---|---|
| **Deliverable** | **Living Labs impact at the NBS level** |
| **Deliverable No.** | 4.9 |
| **Work Package** | 4 |
| **Dissemination Level** | PU |
| **Author(s)** | Chiara Baldacchini, University of Tuscia & CNR, and Carlo Calfapietra, CNR. |
| **Co-Author(s)** | Gabriele Guidolotti, Benedetto Rugani, Michele Mattioni, Martina Della Casa, Dania Valli, CNR; Alessandro Campiotti, University of Tuscia; Giovanni Sanesi, Giuseppina Spano, Elisabetta Ricciardi, UNIBA; Payam Dadvand, Mònica Ubalde, Carmen Peuters, Oriol Planesas, ISGLOBAL; Bernd Pölling, SWUAS; Federica Larcher, Paola Gullino, Simona Bonelli, Monica Vercelli, Chiara Ferracini, Marta Depetris, Luca Battisti, Egidio Dansero, UNITO; Yaoyang Xu, Tian Ruan, IUE-CAS; Marijo Spajic, ZIPS; Sergeji Lugovic, VESELA MOTIKA; Mais Jafari, Dagmar Knappe, DORTMUND; Laura Ribotta, Riccardo Saraco, COTO; Iva Bedenko, Matija Vuger, ZAGREB. |
| **Date** | 28/11/2023 |
| **File Name** | D4.9_Living Labs impact at the NBS level_CNR_2023-11-28 |
| **Status** | |
| **Revision** | |
| **Reviewed by (if applicable)** | Axel Timpe, RWTH; Teresa Ribeiro, CASCAIS. |
| **Information to be used for citations of this report** | Baldacchini, C., Calfapietra, C. (2023): Living Labs impact at the NBS level, Deliverable No.4.9, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 86 pp. |



This project has received funding from the EU's Horizon 2020 research and innovation programme under grant agreement no. 776528.

CONTACT:
Email: **progireg@la.rwth-aachen.de**
Website: **www.proGIreg.eu**

This work was financially supported by the National Key Research and Development Programme of China (2017YFE0119000).

# Contents



# Figures

# Tables

# Partner organisations

| No. | Name | Short name | Country |
|---|---|---|---|
| 1 | Rheinisch-Westfaelische Technische Hochschule Aachen | RWTH | Germany |
| 2 | Stadt Dortmund | DORTMUND | Germany |
| 3 | Comune di Torino | COTO | Italy |
| 4 | Grad Zagreb | ZAGREB | Croatia |
| 20 | Fundacion Privada Instituto de Salud Global Barcelona | ISGLOBAL | Spain |
| 21 | Università degli Studi di Torino | UNITO | Italy |
| 22 | Consiglio Nazionale delle Ricerche | CNR | Italy |
| 24 | Università degli Studi di Bari Aldo Moro | UNIBA | Italy |
| 25 | Fachhochschule Suedwestfalen | SWUAS | Germany |
| 33 | The Forestry Bureau of Ningbo City (FBNC), City | FBNC | China (People's Republic of) |
| 34 | Institute of Urban Environment, Chinese Academy of Sciences | IUE-CAS | China (People's Republic of) |

# Abbreviations

| | |
|---|---|
| Dx.x: | deliverable |
| EC: | European Commission |
| ELMQ: | economic and labour market questionnaire |
| ES: | ecosystem services |
| FC: | Follower City |
| FRC: | Front-Runner City |
| FTE: | full-time equivalent |
| GA: | Grant Agreement |
| GI: | Green Infrastructure |
| GIS: | geographic information system |
| GQ: | general questionnaire |
| HIA: | Health Impact Assessment |
| KPI: | key performance indicator |
| LCA: | life cycle assessment |
| LL: | Living Lab |
| NBS: | nature-based solutions |
| NGO: | non-governmental organization |
| PPP: | public-private-partnership |
| proGIreg: | productive Green Infrastructure for post-industrial urban regeneration |
| SC: | societal challenge |
| SME: | small and medium enterprise |
| WP: | work package |

# Executive Summary

The project entitled “productive Green Infrastructure for post-industrial urban regeneration (proGIreg)” implemented eight different types of nature-based solutions (NBS) in post-industrial sites of four different cities (called front runner cities - FRC). The implemented NBS are rather local, on spatial scale, but, in every FRC, they are networked within a Living Lab (LL) vision that engages a single district. One of the main goals of the project was to assess the benefits produced by the implemented NBS. In the present deliverable, the proGIreg impact assessed at the local (i.e., NBS) scale is presented.

To obtain an overview as comprehensive as possible of the benefits produced by the implemented NBS, four domains have been explored, to assess: 1) socio-cultural inclusiveness; 2) increased health and well-being; 3) ecological and environmental restoration; and 4) economy and labour market benefits.

According to the experimental approach described in the Monitoring and Assessment Plan (Deliverable 4.1 – D4.1), NBS impact is evaluated by local scale key performance indicators (KPIs), in compliance with the guidelines described in the Handbook elaborated by the NBS Impact Evaluation Taskforce of the European Commission. For the calculation of the KPIs, specific monitoring tools have been adopted or developed within proGIreg, to obtain the required data. The acquired data will be made available on the project data platform, while the obtained indicators will be presented in this deliverable, per each monitored intervention (Chapter 3).

The impact evaluated for the single proGIreg NBS interventions is often significant only with respect to a single (or a few) societal challenge. This is likely due to several reasons, among which: i) the NBS intervention has been shaped by focusing on a single (or a few) number of target challenges and aspects related to other possible benefits are underdeveloped, avoiding impact to be measured; ii) the background (surrounding) area provides similar benefits, avoiding those due to the intervention to be disclosed; iii) the delay encountered by the implementation process avoid the impact evaluation; iv) lack of expertise among the local partners involved in data collection.

Nevertheless, thanks to the LL approach, success stories of virtuous NBS (i.e., providing multiple benefits, according to the UNEA definition, 2023) can be identified within the proGIreg project, by grouping into a single narrative the NBS interventions realized in the same site, when possible (Chapter 4).

Moreover, the strategy of replicating similar NBS intervention in the different FRC resulted to be winning to build knowledge on NBS impact, since this allowed to compare the impact obtained by similar intervention realized in different context, as a function of design and implementation parameters (Chapter 5).

This document represents a key deliverable for Work Package 4 (WP4 - “NBS benefit assessment and monitoring”).

# 1. Introduction

## 1.1. Introduction to the project

Productive Green Infrastructure for post-industrial urban regeneration (proGIreg) is developing and testing nature-based solutions (NBS) co-creatively with public authorities, civil society, researchers, and businesses. Eight nature-based solutions, which will support the regeneration of urban areas affected by deindustrialisation, were deployed in Dortmund (Germany), Turin (Italy), Zagreb (Croatia) and Ningbo (China). The cities of Cascais (Portugal), Cluj-Napoca (Romania), Piraeus (Greece) and Zenica (Bosnia and Herzegovina) received support in developing their strategies for embedding nature-based solutions at local level through co-design processes.

## 1.2. Introduction to the deliverable

The NBS implemented during proGIreg aimed at achieving several benefits, in different fields of interest. Work Package (WP) 4 of proGIreg was devoted to the assessment of the benefits produced by the implemented NBS. WP4 was a collaborative action involving local authorities, the civic sector, small-medium enterprises (SMEs), and research institutes, with the aim of providing a significant and comprehensive evaluation of NBS interventions' benefits, which ultimately can be translated into informed policies and targeted interventions aimed at promoting healthy, equitable, sustainable, and economically thriving urban environments.

NBS produced benefits' evaluation has proceeded as a multi-step process, described in detail in the D4.6 – Guidelines for Upscaling[1], among which the most important are:

- Identification of the assessment domains;
- Identification of the spatial and temporal scales of interest;
- Identification of significant key performance indicators (KPIs) and related methods;
- Data collection;
- Indicators' assessment and impact evaluation.

The first three steps of this process have been firstly described in the project Monitoring and Assessment Plan (Deliverable 4.1; D4.1)[2], being developed in line with the guidelines described in 2017 by the EKLIPSE – Expert Working Group on NBS evaluation[3]. However, in 2021, based on the experience gained by the Horizon 2020 NBS projects, including

[1] Ristorini, M., Baldacchini, C. (2022): Guidelines for upscaling, Deliverable No.4.6, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 68.
[2] Baldacchini, C. (2019): Monitoring and Assessment Plan, Deliverable No. 4.1, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 124.
[3] Raymond, B. et al., (2017) An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects. Report prepared by the EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology & Hydrology, Wallingford, United Kingdom.

proGIreg, the NBS Impact Evaluation Taskforce of the European Commission (EC) released the Handbook entitled “Evaluating the impact of Nature-Based Solutions”[4], which presents the most updated knowledge in the field. Thus, the proGIreg benefit monitoring and impact evaluation strategy has been adapted to match with these new guidelines, as described in the D4.5 - Report on benefits produced by implemented NBS[5].

In particular, 12 key societal challenge areas are identified in the Handbook (Figure 1):

1. Climate Resilience
2. Water Management
3. Natural and Climate Hazards
4. Green Space Management
5. Biodiversity Enhancement
6. Air Quality
7. Place Regeneration
8. Knowledge and Social Capacity Building for Sustainable Urban Transformation
9. Participatory Planning and Governance
10. Social Justice and Social Cohesion
11. Health and well-being
12. New Economic Opportunities and Green Jobs


**Figure 1.** Key societal challenge areas identified in the NBS Impact Evaluation Framework (image © Ref. 4).

---

[4] Evaluating the impact of nature-based solutions: A handbook for practitioners, A. Dumitru and L. Wendling Eds, European Union (2021).

[5] Baldacchini, C. (2021): Report on benefits produced by implemented NBS, Deliverable No.4.5, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 146.

For each of the identified societal challenge areas, a list of useful Key Performance Indicators (KPIs, i.e., measurable parameters that demonstrate how effectively an NBS is producing benefits) is reported in the Handbook, with detailed methodology[4]. To provide a holistic description of produced benefits and ensure comparability, per each area, a few indicators are listed in the Handbook as “Recommended”: these are the indicators that, when possible, each Horizon 2020 NBS project should assess. A further long list of “Additional” indicators is also provided, to match specific project needs.

Within this framework, the four assessment domains identified as priorities for the NBS implemented in proGIreg by D4.1 (Figure 2) match the above-mentioned societal challenge areas as follow:

- “Socio-cultural inclusiveness” mainly relates to areas 8,10 and 11;
- “Human health and well-being” matches area 4 and 11;
- “Ecological and environmental restoration” includes areas 1, 2, 4, 5, and 6;
- “Economic and labour market benefits” matches area 12.

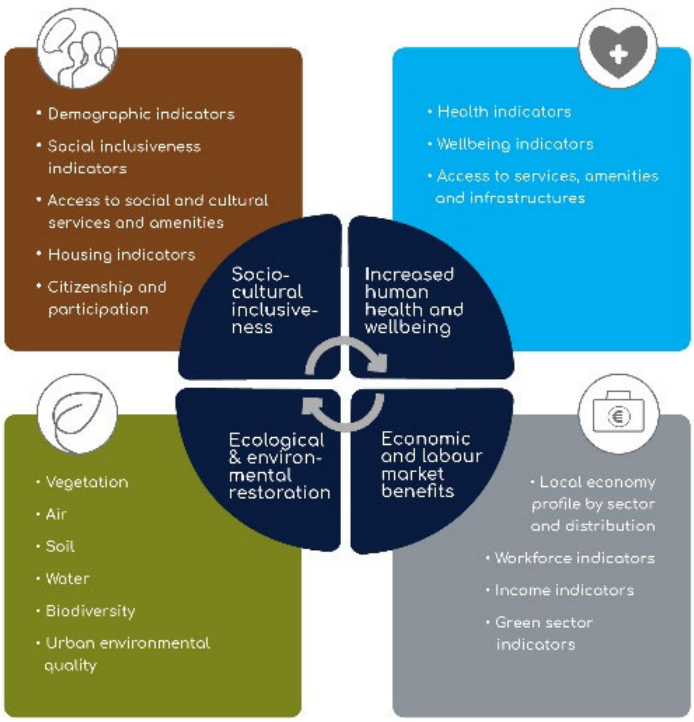



**Figure 2.** ProGIreg assessment domains (image © ICLEI).

Per each domain, there is a corresponding Task in WP4, handled by a proGIreg scientific partner having a clear expertise in the related field. Namely:

- **Task 4.1: Assessing socio-cultural inclusiveness, led by UNIBA -** The available studies indicate a profound and multifaceted connection between nature and social impact[6]. Exposure to natural environments, such as parks and green spaces, has been linked to improved mental health, reduced stress, and a sense of well-being. These benefits, in turn, contribute to stronger community cohesion and increased physical activity, addressing issues like anxiety, depression, and obesity. Moreover, environmental education programs enhance cognitive development, nurturing environmental responsibility. Additionally, nature-based tourism and outdoor recreation boost the economy and provide jobs, while preserving natural habitats is crucial for biodiversity, agriculture, and medicine resources. These findings highlight the pivotal role of nature in shaping our society and well-being. This task aimed at assessing indicators of socio psychological benefits, such as connectedness to nature, mindfulness, social interaction and cohesion, and perceived restorativeness of NBS, in the LL district citizens and among the users of specific NBS. Moreover, the liveability of the LL district has been also assessed by the Walkability Index, an objective measure of how much a particular area is more or less likely to be walkable by people. It provides additional information on the urban structure of cities and districts.
- **Task 4.2: Increased human health and well-being, led by ISGLOBAL** - Previous evidence has shown an association between exposure to greenspace and improved physical and psychological outcomes, including cardiovascular health, stress levels, and cognitive functioning[7]. However, the knowledge on the public health benefits that new nature solutions in urban settings (such as providing access to a riverbank, or a new park) may provide still deserve a strong interest. The evaluation of newly implemented NBS allows to estimate the potential health and well-being benefits. The collected data include indicators on physical activity and time spent in and perceived quality and satisfaction of the NBS. Additionally, the number and demography of visitors and their physical activity levels in the surroundings of the implementation sites is assessed. In addition, to estimate health benefits of NBS conducted in the context of proGIreg, Health Impact Assessment (HIA) tools have been used to quantify the number of deaths that can be prevented by NBS implementation. The HIA tools can be used to upscale the findings by predicting health benefits of future NBS and different “scenarios”.
- **Task 4.3: Ecological and environmental restoration, led by CNR** - Green Infrastructures (GI), provide to citizens several environmental services thanks to the interactions that establish with the surrounding environment[8]. At global scale, there are direct and indirect interactions with the carbon biogeochemical cycle. GI can directly remove carbon dioxide ($CO_2$) from the atmospheric pool and, thanks to temperature regulation, the energy demand can be reduced. At local scale, the major benefits are related to air quality and micro-climate regulation and to biodiversity enhancement. Indeed, GI impacts air pollution formation and deposition by removing oxides and other secondary pollutants as ozone through stomata and particulate matter (PM) by wet and dry deposition on leaf surfaces, while providing at the same time suitable habitats for plant and animals. This task aimed at assessing the impact of proGIreg approach on the greenness of the LL districts, while several environmental benefits related to the above-mentioned ecosystem services (ES) are assessed at the NBS level. Finally, the environmental impact over their whole life cycle of NBS implementation including innovative

[6] Arbuthnott, K. D. (2023), Nature exposure and social health: Prosocial behavior, social cohesion, and effect pathways, J. Environ. Psychol., 90, 102109.
[7] Jimenez, M. P. et al., (2021) Associations between Nature Exposure and Health: A Review of the Evidence. Int. J. Environ. Res. Public Health,18, 4790.
[8] Pereira, P. and Baró, F., (2022) Greening the city: Thriving for biodiversity and sustainability, Science of The Total Environment 817, 153032.

technologies for the sustainable use of natural resources, such as soil regeneration and aquaponics, has been evaluated.

- **Task 4.4: Economic and labour market benefits, led by SWUAS** - Extensive research has shown that expanding GI in cities and wider metropolitan areas is accompanied by multiple direct and indirect economic and labour benefits[9]. Effects such as increased real estate values, new commercial initiatives, new (and frequently green) job opportunities and new business opportunities, among others, are all possibilities when implementing NBS in a city. This task aims to quantify the economic and labour market (co-)benefits of the project's NBS implementations in the FRC, both in the general district population and among the users of specific NBS implementations.

The Task responsible partners oversaw planning of the monitoring activities, trained the data collectors, and analysed the data. Local partners (coordinated by the FRC) have been responsible for data collection. The coordination of the WP4 activities was supervised by CNR. A graphical representation of the partners involved in WP4 is shown in Figure 3.

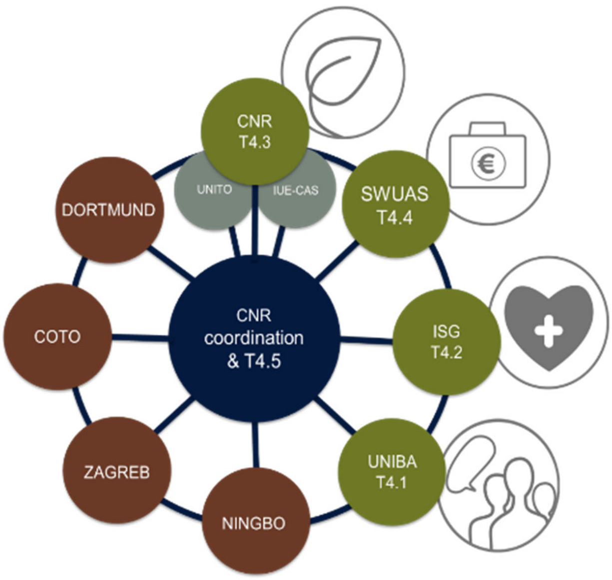



**Figure 3.** WP4 partners. Task responsibilities are highlighted, together with the corresponding assessment domains, represented by icons (image © ICLEI).

Per each assessment domain, the leading scientific partners have identified the spatial and temporal scales of interest[2], and the protocols of measurements[10]. The impact of the implemented NBS has been mainly assessed at the local (i.e., NBS) scale, and the obtained results are presented in this deliverable. However, being the NBS interventions networked within a Living Lab (LL) vision that engages a single district, the impact at the LL district scale has been also evaluated, and it is discussed in D4.8 "Living Lab impact at the district scale"[11].

[9] Shakya, R. et al., (2021) A Synthesis of Social and Economic Benefits Linked to Green Infrastructure, Water 13, 3651.

[10] Baldacchini, C. (2019): Protocols of Measurements, Deliverable No.4.3, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 39 pp.

[11] Baldacchini, C. (2023): Living Labs impact at the district level, Deliverable No.4.8, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission, 92 pp.

To evaluate the impact at NBS level of the proGIreg implementations, research partners have developed 10 NBS-level monitoring tools[2], which allow to obtain one or more KPIs[5], each (Chapter 2). Such tools have been used to collected data from NBS implementations selected based on their spatial and temporal scales (which should be significant, as described in D4.3[10]). The list of the monitored NBS and the related monitoring activities have been updated several times during the project, being the protocol of measurement to be intended as a living, resilient document, able to adapt to changes in the NBS implementation plans (likely due, for instance, to administrative barriers and natural hazards), or to the lack of specific expertise among the local partners, as described in the D4.5[5]. Nevertheless, the impact evaluation of at least one case study per NBS type per FRC has been performed, when possible, and in connection with more societal challenges as possible. The final list of the evaluated NBS implementations, with the corresponding obtained KPIs, is reported in Chapter 3.

However, the impact evaluated for the single proGIreg NBS intervention is often significant only with respect to a single (or a few) societal challenge. This is likely due to several reasons, among which: i) the NBS intervention has been shaped by focusing on a single (or a few) number of target challenges and aspects related to other possible benefits are underdeveloped, avoiding impact to be measured; ii) the background (surrounding) area provides similar benefits, avoiding those due to the intervention to be disclosed; iii) the delay encountered by the implementation process avoid the impact evaluation; iv) lack of expertise among the local partners involved in data collection.

Nevertheless, thanks to the LL approach, success stories of virtuous NBS (i.e., providing multiple benefits, according to the UNEA definition, 2023[12]) can be identified within proGIreg, by grouping into a single narrative the NBS interventions realized in the same site, when possible (Chapter 4).

Moreover, the strategy of replicating similar NBS intervention in the different FRC resulted to be winning to build knowledge on NBS impact, since this allowed to compare the impact obtained by similar intervention realized in different context, as a function of design and implementation parameters (Chapter 5).

# 2. NBS types, monitoring tools and KPIs

During the proGIreg project, eight different types of NBS are implemented and monitored to assess their benefits (Figure 4). Not all the NBS types are implemented in all FRCs, given to local settings and available expertise. The name and description of the different NBS types

[12] United Nations Environment Assembly of the United Nations Environment Programme, UNEP/EA.5/Res.5 (2023)

are described in detail in D3.2 ("Four Implementation Plans: Dortmund, Turin, Zagreb, Ningbo")[13], and are labelled as:

- NBS1: Leisure activities and clean energy on former landfills;
- NBS2: New regenerated soil;
- NBS3: Community-based urban farms and gardens;
- NBS4: Aquaponics;
- NBS5: Green walls and roofs;
- NBS6: Accessible green corridors;
- NBS7: Local environmental compensation processes;
- NBS8: Pollinator biodiversity.

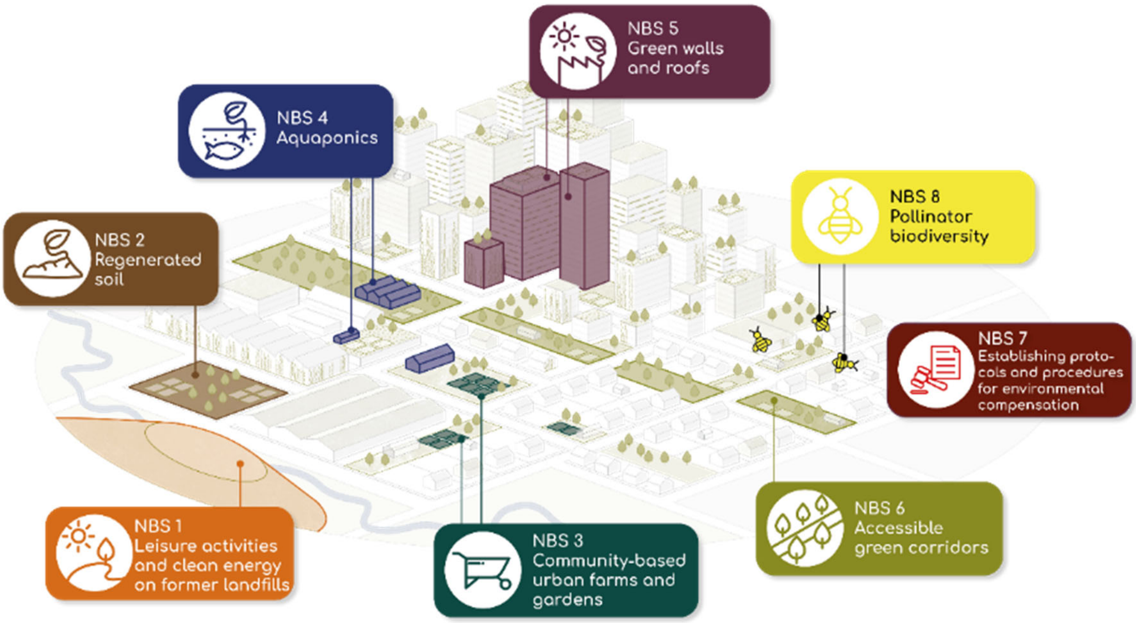



**Figure 4.** Eight NBS typologies being implemented in the proGIreg FRC (image © RWTH Institute of Landscape Architecture).

The experimental activity at NBS level has involved the four assessment domains. The experimental tools developed to assess benefits at the NBS level are resumed in Table 1, with a short description of the data collection process and of the obtained KPIs. Most of the KPIs have been assessed in compliance with the European assessment framework[4], but also KPIs not included in the framework have been used, when required. This list has been slightly changed with respect to what reported in D4.5[5] during the data analysis phase, based on real data availability.

[13] Saraco, R. (2020): FRC Implementation Plans, Deliverable No. 3.2, proGIreg. Horizon 2020 Grant Agreement No 776528, European Commission

**Table 1.** NBS level monitoring tools applied during proGIreg with description of data type and collection methods, corresponding societal challenge (SC) and key performance indicators (KPIs), with a short description. Per each indicator, it is also specified if it is included in (or adapted from) the EC Handbook[4] (the corresponding indicator number is reported) and if it is "Recommended" (R) or "Additional" (A).

| NBS-level monitoring tool | Data type and data collection | SC | KPIs (R/A) | Description |
|---|---|---|---|---|
| A – NBS visitor questionnaire | Anonymous survey to be performed 24 months after NBS implementation. Exceptions have been made for samples composed of vulnerable populations (see paragraph 5.4 for further details). | 4 | 8.31.3 Number of and reasons for visits to an NBS area (A) | Visits means discretionary time, ranging from a few minutes out of the home to an all-day trip. Visits may include time spent close to home or further afield, potentially while on holiday |
| | | 8 | Pro-environmental attitude (not in the Handbook[4]) | An individual's concern for the natural environment reflecting common attitudes and opinion towards the ecological environment |
| | | 8 | 15.4. Pro-environmental behaviour (R) | A behaviour which is generally judged a behaviour with a significant impact of the environment and a tribute to the healthy environment |
| | | 10 | 20.2 Perceived social interaction (A) | Sequence of social actions between individuals or groups who modify their actions and reactions due to actions by their interaction partner(s)<br><br>It is measured by the % of respondents that declared that they had social interactions |
| | | 10 | 20.4.2. Perceived social support (A) | Perception of various ways in which individuals aid others, scored 0-24. |
| | | 10 | 20.5. Perceived social cohesion (A) | Social cohesion indicates the set of behaviours and bonds of affinity and solidarity between individuals or groups.<br><br>Participants respond at the single item: "To what extent do you think that this NBS have contributed to improving and increasing relations with your neighbours?" on the following scale: "A lot", "Quite a bit", "A little", "Not at all". |
| | | 11 | 22.13. Perceived restorativeness of NBS (A) | Perception of restoration coming from an NBS, scored 0-45. |

| | | | | |
|---|---|---|---|---|
| | | 11 | 22.1 Self-reported physical activity (A) | Self-reported physical activity in average time spent performing the activity level [Walking, Moderate, Vigorous] |
| B –SOPARC | Survey performed by using the “System for Observing Play and Recreation in Communities”[14], post intervention, and when possible, in a pre/post-implementation design | 4 | 8.31.2 Number of visitors in new recreational areas (A) | The amount of people visiting, for leisure purpose over a year, the area where the new infrastructure (both NBS, hybrid solutions and grey infrastructures) is implemented. |
| | | 11 | 22.2 Observed physical activity levels within NBS (A) | Observed weekly physical activity in the NBS (sedentary, walking, or vigorous) |
| C – Economic and labour market questionnaire (ELMQ) | Survey about economic parameters to be submitted to the organisation in charge of NBS implementation and long-term management | 12 | 23.3 Direct economic activity: Number of new jobs created (R) | Number of full-time equivalents (FTE) or jobs created for and after implementation (i.e., for planning, construction or the long-term maintenance of the NBS) |
| | | 12 | 24.5 NBS cost/benefit analysis: Initial costs (A) | Cost of the NBS implementation discounting labour costs mentioned above. With breakdown into costs of permissions/licences, construction material and other equipment, land access, machinery rental, usage fees, taxes, etc. |
| | | 12 | 24.6 NBS cost/benefit analysis: Maintenance costs (A) | Maintenance expenses are the costs incurred to keep an item in good condition, good working order or for the evolution of an implemented NBS. This total maintenance cost must include total annual labour costs, land leasing costs, machinery, energy costs, licensing, etc. |
| | | 12 | 24.34 Value of food produced in NBS (A) | Income obtained from the sale of the food produced (honey, fruits/veg, fish, etc). If no income produced- market value of food produced and distributed by other means (donation, sharing, etc.) |
| | | 12 | 24.35 Renewable energy produced in NBS (A) | Energy produced by NBS with photovoltaic systems |

[14] McKenzie et al., (2006). System for Observing Play and Recreation in Communities (SOPARC): Reliability and Feasibility Measures. J. Phys. Act. Health 3 Suppl 1, S208-S222.

| | | | | |
|---|---|---|---|---|
| | | 12 | Number of beneficiaries (not in the Handbook[4]) | Estimated number of beneficiaries taking advantage of the implemented NBS |
| | | 12 | Financial revenues (not in the Handbook[4]) | Amount of financial revenues or breakdown into sales of goods and services, fees, rents |
| D – Carbon impact | Data on energy production by photovoltaic systems will be converted in $CO_2$ equivalent | 1 | Avoided greenhouse gas emissions from renewable energy production<br><br>Adapted from 1.2 (R) | $CO_2$ emissions avoided to produce the same amount of energy using renewable systems |
| | Elaboration through a semi-empirical model based on tree biometric data (*i-Tree Eco*[15]) to obtain information on the carbon storage in specific NBS | 1 | 2.1.1 Carbon storage and sequestration in vegetation per unit area per unit time (A) | Total amount of carbon (tonnes) stored in vegetation, described per unit area and unit time |
| E – Air Quality | Elaboration through semi-empirical models of environmental data, to obtain information on the amount of air pollutants removed by vegetation | 6 | 12.1 Removal of atmospheric pollutants by vegetation (A) | Amount of air pollutants ($PM_{2.5}$, $PM_{10}$, $CO_2$, $O_3$, $NO_2$) removed by vegetation (in stem, leaves and roots) per unit area and unit time (kg ha-1 year-1) |
| | Discontinuous concentration measurements by passive diffusion tubes in the proximity of the NBS and in a control site, repeated before and after the implementation, in three replicates for both the NBS and the control sites | 6 | 12.7 Concentration of particulate matter ($PM_{10}$ and $PM_{2.5}$), $NO_2$, and $O_3$ in ambient air (A) | Concentration of $NO_2$ and ground-level $O_3$ (μg/m$^3$) in ambient air (concentration of $PM_{10}$ and $PM_{2.5}$ has been not monitored by this tool) |
| F – Air temperature | Continuous measurement of air temperature inside an NBS and in a control site over three years; for each monitoring site, 6 temperature sensors are used (3 for the NBS site and 3 for the control site) | 1 | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | Difference between the monthly average daily maximum temperatures observed during the warmest month, on a yearly base:<br>– in the NBS site and in a control site, for urban park, garden etc.<br>– inside and outside the building where the NBS is located, for green walls and roofs |
| | | 1 | Mitigation of daily minimum temperature<br><br>Adapted from 1.4 (R) | Difference between the monthly average daily minimum temperatures observed during the coldest month, on a yearly base: |

[15] https://www.itreetools.org/, Hirabayashi, Satoshi, Charles N. Kroll, and David J. Nowak. "i-Tree eco dry deposition model descriptions." Citeseer (2012).

| | | | | |
|---|---|---|---|---|
| | | | | – in the NBS site and in a control site, for urban park, garden etc.<br>– inside and outside the building where the NBS is located, for green walls and roofs |
| G – PM biomonitoring | Leaf-deposited PM estimation, using scanning electron microscopy coupled with energy-dispersed x-ray spectroscopy (SEM/EDX)[16], to be repeated twice during the project | 6 | 12.2 Total particulate matter (PM) removed by NBS vegetation (A) | The PM removed by deposition on the leaves of trees and shrubs in the NBS site is characterized in terms of density, size distribution, chemical composition and daily load (daily mass per unit leaf area). The upscaling of the obtained results provides an estimation of the total removed PM by the NBS, at the required time scale. |
| H – Environmental footprint | Approach based on life cycle assessment (LCA) principles to account for the multiple environmental impacts associated with the NBS life cycle activities<br><br>* the definition and the indicators associated with this tool are changed through the project, to make it more general as application and more focused on LCA as methodology | 1 | Avoided greenhouse gas emissions due to the introduction of the NBS, with respect to business-as-usual (grey) solutions<br><br>Adapted from 1.2 (R) | Total amount of saved greenhouse gas (GHG) emissions due to the introduction of the NBS, with respect to business-as-usual (grey) solutions; avoided GHGs are accounted for in t CO2eq. considering the lifetime and the total life cycle activities of the compared systems |
| | | 5* | 10.15 Equivalent used soil (A) | Total amount of fertile soil saved by using the soil regeneration procedures proposed within the NBS<br>*this indicator belongs to SC 5, but it is also related to SC 4 |
| | | 6 | Modelled NOx and PM in gaseous releases along the NBS lifecycle<br><br>Adapted from 12.4 (A) | Modelled air pollutant emissions of NOx and PM associated with the life cycle activities of the NBS; these emissions are accounted for in kg $PM_{2.5}$-eq./ha of NBS area, and their release trend is estimated over the lifetime of the NBS |
| | | 6 | Modelled trends in emissions of $NO_X$ and $SO_X$<br><br>Adapted from 12.6 (A) | Measure air concentrations of $NO_x$ and $SO_x$ in µg/m$^3$ at identified sampling points close to planned nature-based interventions and highway improvement schemes both pre- and post-intervention. Compare these data for differences, and also compare these data to historical city-wide data to identify trends |
| I – Biodiversity | In Turin, biodiversity monitoring surveys of | 5 | 9.4 Species diversity within defined area | The Shannon Diversity index provides more information about |

[16] Baldacchini, C. et al. (2019), An ultra-spatially resolved method to quali-quantitative monitor particulate matter in urban environment, Environmental Science and Pollution Research 26, 18719 – 18729.

| | | | | |
|---|---|---|---|---|
| | selected pollinator species were performed according to specific protocols adapted to NBS and observers, and repeated once a week during the pollinators' season, and repeated for 3 years during the project<br><br>In Ningbo, plankton sampling was conducted once a week, along the project duration, by collecting water at 3 points set at the inlet, outlet and centre of the restoring lake | | per Shannon Diversity Index (R) | the fauna and flora composition than simply area richness. It takes into consideration both the number of different species observed and their relative abundances |
| | | 5 | 9.5 Number of species within defined area per Shannon Evenness Index (R) | The Shannon Evenness Index provides information about area comparison and species richness. It gives information about homogeneity of individual distribution between species in the community |
| J – Water quality | Three water samples are collected every week in significant sampling points; transparency, water temperature, pH, dissolved oxygen, total suspended solids, chemical oxygen demand, total phosphorus, total nitrogen, chlorophyll, ammonia nitrogen are determined | 2 | 3.3 Water quality: TSS content (R) | Total suspended solids (TSS) or turbidity (%, mg/L and total; units dependent upon measurement technique). A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids" |
| | | 2 | 3.4 Nitrogen and phosphorus concentration or load (R) | Nitrogen and phosphorus in surface water and/or groundwater (%, expressed as total annual N or P load and/or reduction of maximum annual concentration) |
| | | 2 | Chlorophyll-a content<br><br>Related to 4.33 Eutrophication (A) | Chlorophyll-a content >10 $mg/m^3$ indicates water eutrophication |

# 3. NBS case studies and obtained KPIs

The NBS case studies for which impact assessment at the NBS level has been obtained, and the corresponding KPIs, are presented in the following tables, grouped by FRC in different subchapters. The addressed societal challenges are also reported. The following KPIs, as well as the datasets from which they have been obtained, are also present in the project data platform (www.progiregdata.eu). For those indicators that have been calculated based on data monitored over a long period, the averaged values measured at the beginning and at the end of the monitoring activities (averaged over a similar period, in terms of time period and seasonality) are reported as KPI. For those indicators that have been obtained by questionnaires, suitable personal data protection actions have been put into action, and only aggregated, anonymized data are available in the platform.

Almost all the NBS implementations selected for impact assessment along the project have been finally evaluated, with few exceptions, such as NBS2 in Ningbo (which was not realized due to environmental issues) or NBS7 in the three cities (since they were mostly self-standing public financial or governance interventions, by definition, whose evaluation would have required ad hoc tools not implemented).

## 3.1. NBS implementations monitored in the Dortmund Living Lab

**Table 2.** Dortmund NBS1.1: Integrating solar energy production on Deusenberg landfill, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Dortmund NBS1.1: Integrating solar energy production on Deusenberg landfill** | 1. Climate Resilience | Avoided greenhouse gas emissions from renewable energy production<br><br>Adapted from 1.2 (R) | 2246 tonnes/y of saved $CO_2$ | Calculated from indicator 24.35 |
| | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created (R) | • 20 persons in co-design and implementation<br>• 0.3 FTE in maintenance | Low job for maintenance since mainly self-sustaining system |
| | | 24.5 NBS cost/benefit | 2.6 M€ | Implementation costs |

| | | | | |
|---|---|---|---|---|
| | | analysis: Initial costs | | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | 5000 €/year | |
| | | 24.35 Renewable energy produced in NBS | 3700000 kWh/y of electrical energy | |
| | | Number of beneficiaries | Many | Not specifiable any further |
| | | Financial revenues | 320000 €/year | |

**Table 3.** Dortmund NBS1.2: Exercise Park in Huckarde, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Dortmund NBS1.2: Exercise Park in Huckarde** | 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | PRE: 143 ± 50<br>POST: 143 ± 31 | Mean (SD) number of visitors per day counted at pre- and post-implementation of the NBS (SOPARC). |
| | | 8.31.3 Number of and reasons for visits to an NBS area | 5 ± 5 visits per month 60% walking, 30% socializing, 6% quiet activities | Median (IQR) number of visits to NBS area and main activity (N=67) |
| | 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | 25,4% | 25,4% of respondents declared that they had social interactions |
| | | 20.4.2. Perceived social support | 14,3 | the total score of perceived social support was high (max score = 24) |

| | | | | |
|---|---|---|---|---|
| | | 20.5. Perceived social cohesion | 70,14% “quite a bit” | The majority of respondents (70,4%) declared that perceived social cohesion among neighbours was increased “quite a bit” |
| | 11. Health and well-being | 22.1 Self-reported Physical activity | Walking: 31 ± 18 min<br>Moderate: 20 ± 14 min<br>Vigorous: 60 ± 0 min | Average time (mean ± SD) performing the activity level on the days in which the activity was performed (N=67) |
| | | 22.2 Observed physical activity levels within NBS | PRE:<br>sedentary: 25<br>walking: 103<br>vigorous activity: 13<br><br>POST:<br>sedentary: 15<br>walking: 101<br>vigorous activity: 26 | Average number of visitors per day counted at pre- and post-implementation of the NBS (SOPARC) |
| | | 22.13. Perceived restorativeness of NBS | 31 | The total score of perceived restorativeness was high (max score = 45) |

**Table 4.** Dortmund NBS3.1: Food forests and permaculture orchard in Huckarde, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Dortmund NBS3.1: Food forests and permaculture orchard in Huckarde (St. Urbanus)** | 1. Climate Resilience | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | Delta$T_{max}$ (July 2020) -0.46 ± 4.08 °C<br><br>Delta$T_{max}$ (July 2021) 1.47 ± 2.55 °C<br><br>Delta$T_{max}$ (July 2022) -0.39 ± 4.35 °C | Monthly mean of daily maximum temperature of NBS site minus the monthly mean of maximum temperature at control site at beginning (July 2020), at intermediate (July 2021) and at the end (July 2022) of the acquiring period (8/11/19 to 25/07/22)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |

| | | | |
|---|---|---|---|
| | Mitigation of daily minimum temperature<br><br>Adapted from 1.4 (R) | DeltaT$_{min}$ (January 2020) -0.22 ± 4.17 °C<br><br>DeltaT$_{min}$ (January 2021) -2.67 ± 2.21 °C<br><br>DeltaT$_{min}$ (January 2022) -2.42 ± 3.98 °C | Monthly mean of daily minimum temperature of NBS site minus the monthly mean of daily minimum temperature at control site at beginning (January 2020), at intermediate (January 2021) and at the end (January 2022) of the acquiring period (8/11/19 to 25/07/22)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |
| 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | 30 ± 12 per day | Mean (SD) number of visitors at post-implementation of the NBS (SOPARC). |
| | 8.31.3 Number of and reasons for visits to an NBS area | 3 ± 3 visits per month<br>82% gardening, 12% quiet activities | Median (IQR) number of visits to NBS area and main activity (N=34) |
| 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Not upscaled at the NBS level since very few trees are present<br><br>Mean removed $PM_{10}$ daily load by trees is:<br><br>• 0.41 ± 0.10 ug/cm$^2$ for *C. betulus*<br>• 0.16 ± 0.02 ug/cm$^2$ for *Cornus spp.*<br>• 0.25 ± 0.03 ug/cm$^2$ for *C. avellana*<br>• 0.24 ± 0.05 ug/cm$^2$ for *R. pseudacacia* | Data acquired in 01/09/2020<br>Closest intense rain event before sampling date: 15/08/2020<br><br>Uncertainty is Standard Error |
| | 12.7 Concentration of particulate matter (PM10 and PM2.5), $NO_2$, and $O_3$ in ambient air | $O_3$ in NBS (ppb):<br>37.6 ± 4.7,<br>25.0 ± 1.4,<br>38.1 ± 2.0<br><br>$O_3$ in control site (ppb):<br>36.5 ± 4.3,<br>19.9 ± 1.1,<br>38.2 ± 1.9<br><br>$NO_2$ in NBS (ppb):<br>8.9 ± 0.3,<br>8.1 ± 0.2,<br>10.1 ± 0.7 | Sampling periods:<br>14/06/2019 to 03/07/2019, 02/07/2021 to 22/07/2021, 29/07/2022 to 19/08/2022<br><br>No statistically significant difference between the control and the NBS for $O_3$<br>Higher $NO_2$ concentration in NBS every year |

| | | | | |
|---|---|---|---|---|
| | | | $NO_2$ in control site (ppb):<br>7.7 ± 0.4<br>6.1 ± 0.2<br>6.8 * | Uncertainty is Standard Error<br><br>*Only one available sample |
| | 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | 47% | % of respondents declared that they had social interactions |
| | | 20.4.2. Perceived social support | 20.1 | the total score of perceived social support was very high (max score = 24) |
| | | 20.5. Perceived social cohesion | 53% “quite a bit” | The majority of respondents (53%) declared that perceived social cohesion among neighbours was increased “quite a bit” |
| | 11. Health and well-being | 22.1 Self-reported Physical activity | Walking: 60 ± 0 min<br>Moderate: 52 ± 26 min<br>Vigorous: 68 ± 31 min | Average time (mean ± SD) performing the activity level on the days in which the activity was performed (N=34) |
| | | 22.2 Observed physical activity levels within NBS | sedentary: 17<br>walking: 77<br>vigorous activity: 22 | Average number of visitors per day counted at post-implementation of the NBS (SOPARC) |
| | | 22.13. Perceived restorativeness of NBS | 33.9 | the total score of perceived restorativeness was high (max score = 45) |
| | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created (R) | • 8 persons involved in co-design/planning<br>• no job for the maintenance | Maintenance is based on volunteers |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 10000 € | |
| | | 24.6 NBS cost/benefit | 500 €/year | |

| | | | | |
|---|---|---|---|---|
| | | analysis: Maintenance costs | | |
| | | 24.34 Value of food produced in NBS | Not yet quantifiable | |
| | | Number of beneficiaries | 500 | |
| | | Financial revenues | Not yet quantifiable, about to start some minor sales in 2024 (honey, jam, fresh produce) | |

**Table 5.** Dortmund NBS4: Aquaponics, related societal challenges and key performance indicators (KPIs). The planned impact assessment in term of environmental footprint by LCA (tool H) has not been performed due to delay in implementation. KPIs 24.34 Value of food produced in NBS and Financial revenues are not yet quantifiable: a rental concept "rent a raft" is planned, added with sales, but no figures yet.

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Dortmund NBS4: Aquaponics** | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created (R) | • 10 persons involved in co-design/planning<br>• 0.5 FTE for the maintenance/running of the system | |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 250000 € | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | 5000 €/year | Land rent ca 1000 €; ca. 2500 € fish and feed; ca. 1000 € plants; plus ca. 500 € energy, water. |
| | | Number of beneficiaries | 500 | |

**Table 6.** Dortmund NBS6: Connection Huckarde with renatured Emscher river and Deusenberg sites, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Dortmund NBS6: Connection Huckarde with renatured Emscher river and Deusenberg sites** | 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | PRE: 3 ± 1 per day<br>POST: 18 ± 8 per day | Mean (SD) number of visitors at pre- and post-implementation of the NBS (SOPARC). |
| | 11. Health and well-being | 22.2 Observed physical activity levels within NBS | PRE:<br>sedentary: 0<br>walking: 13<br>vigorous activity: 0<br><br>POST:<br>sedentary: 1<br>walking: 41<br>vigorous: 8 | Average number of visitors per day counted at pre- and post-implementation of the NBS (SOPARC) |

**Table 7.** Dortmund NBS8: Pollinator biodiversity, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Dortmund NBS8: Pollinator biodiversity** | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created | • 3 persons involved in co-design/ planning with their jobs<br>• 0.3 FTE in the maintenance | one person is involved with a part-time activity in maintenance (depending on the number and area of flower meadows, this will change) |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 3000 € | Seeds ca 2000 €; promotion material/flyer 1000 € |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | Maintenance costs are lower than for frequently mown green park lawns | Only in a few years' time it will be possible to quantify this |
| | | Number of beneficiaries | Many | Not quantifiable since it is not recorded how many benefit (public, frequently used/passed areas) |

## 3.2. NBS implementation monitored in the Ningbo Living Lab

**Table 8.** Ningbo NBS3: Planting aquatic plants along the shore of the lake, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Ningbo NBS3: Planting aquatic plants along the shore of the lake** | 2. Water Management | 3.3 Water quality: TSS content (R) | 6.55 ± 3.22 mg/L (December 2019) 10.4 ± 4.2 mg/L (December 2020) 5.0 ± 1.4 mg/L (December 2021) | Acquired continuously from January 2019 to December 2021<br><br>Uncertainty is Standard Deviation |
| | | 3.4 Nitrogen and phosphorus concentration or load (R) | Total Nitrogen: 1.06 ± 0.34 mg/L (December 2019) 2.33 ± 1.03 mg/L (December 2020) 1.69 ± 0.83 mg/L (December 2021)<br><br>Total Phosphorus: 0.15 ± 0.06 mg/L (December 2019) 0.09 ± 0.02 mg/L (December 2020) 0.10 ± 0.08 mg/L (December 2021) | Acquired continuously from January 2019 to December 2021<br><br>Uncertainty is Standard Deviation |
| | | Chlorophyll-a content<br><br>Related to 4.33 Eutrophication (A) | Chlorophyll-a content: 19.17 ± 6.58 mg/m$^3$ (December 2019) 6.6 ± 5.3 mg/m$^3$ (December 2020) 7.74 ± 2.65 mg/m$^3$ (December 2021) | Acquired continuously from January 2019 to December 2021<br><br>Uncertainty is Standard Deviation |
| | 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | 328 ± 47 per day | Mean (SD) number of visitors at post-implementation of the NBS (SOPARC). |
| | | 8.31.3 Number of and reasons for visits to an NBS area | 13.5 ± 25 visits per month 51% walking, 24% informal games and sports | Median (IQR) number of visits to NBS area and main activity (N=78) |
| | 5. Biodiversity Enhancement | 9.4 Species diversity within | Shannon Diversity Index of phytoplankton at the phylum level: | Phytoplankton monitored were sampled every three |

| | | | |
|---|---|---|---|
| | a defined area (R) | 2019: 1.625 (mean 1.31)<br>2020: 1.281 (mean 1.14)<br>2021: 1.260 (mean 1.03) | months from January 2019 to December 2021 |
| | 9.5 Number of species within a defined area (R) | Shannon Evenness Index of phytoplankton at the phylum level:<br><br>2019: 0.835 (mean 0.71)<br>2020: 0.715 (mean 0.71)<br>2021: 0.648 (mean 0.60) | Phytoplankton monitored were sampled every three months from January 2019 to December 2021 |
| 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Mean removed $PM_{10}$ daily load:<br><br>• 1.43 ± 0.22 μg/cm$^2$ for *A. calamus*<br>• 0.72 ± 0.06 μg/cm$^2$ for *C. glauca* | Data acquired on 12/08/2020, after 7 days from the last rain event<br><br>Not repeated due to project time constrains<br><br>Uncertainty is Standard Error |
| 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | 42,3% | 42,3% of respondents declared that they had interactions |
| | 20.4.2. Perceived social support | 19.3 | the total score of perceived social support was very high (max score = 24) |
| | 20.5. Perceived social cohesion | 48,5% "quite a bit" | The majority of respondents (48.5%) declared that perceived social cohesion among neighbours was increased "quite a bit" |
| 11. Health and well-being | 22.1 Self-reported Physical activity | Walking: 19.5 ± 38.3<br>Moderate: 43.6 ± 91.1<br>Vigorous: 2.3 ± 15.1 | Average time (mean ± SD) performing the activity level on the days in which the activity was performed (N=78) |
| | 22.2 Observed physical activity levels within NBS | sedentary: 160<br>walking: 102<br>vigorous: 66 | Average number of visitors per day counted at post-implementation of the NBS (SOPARC) |
| | 22.13. Perceived | 39.2 | total score of perceived restorativeness was very high |

| | | | | |
|---|---|---|---|---|
| | | restorativeness of NBS | | (max score = 45) |
| | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created | 31 persons involved in co-design/ planning with their jobs; no indications of FTE possible | |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 530,632 € | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | 15,775 €/year | |
| | | Number of beneficiaries | >25,000 | |
| | | Financial revenues | Non | Fully funded by the state government; no financial revenues |

## 3.3. NBS implementations monitored in the Turin Living Lab

**Table 9. Turin** NBS2: New soil in Sangone Park, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS2: New soil in Sangone Park** | 1. Climate Resilience | Avoided greenhouse gas emissions due to the introduction of the NBS, with respect to business-as-usual (grey) solutions | 32 tonnes $CO_2$eq.<br><br>The total amount of the potentially generated carbon footprint after three years of NBS lifetime (considering upstream, implementation and management phases) is about 74 tonnes $CO_2$eq. per 1200 sqm. of NBS | Estimated amount of GHG emissions potentially saved, in total, by using the New Soil instead of exploiting fertile soils from agricultural areas |

| | | | |
|---|---|---|---|
| | Adapted from 1.2 (R) | | |
| | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | $DeltaT_{max}$ (July 2020) -0.53 ± 4.51 °C<br><br>$DeltaT_{max}$ (July 2021) 0.01 ± 3.17 °C<br><br>$DeltaT_{max}$ (July 2022) -0.43 ± 3.52 °C | Monthly mean of daily maximum temperature of NBS site minus the monthly mean of daily maximum temperature at control site at beginning (July 2020), at intermediate (July 2021) and at the end (July 2022) of the acquiring period (13/02/20 to 29/03/23)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |
| | Mitigation of daily minimum temperature<br><br>Adapted from 1.4 (R) | $DeltaT_{min}$ (January 2021) -0.08 ± 2.85 °C<br><br>$DeltaT_{min}$ (January 2022) 0.58 ± 3.06 °C<br><br>$DeltaT_{min}$ (January 2023) -0.56 ± 5.51 °C | Monthly mean of daily minimum temperature of NBS site minus the monthly mean of daily minimum temperature at control site at beginning (January 2021), at intermediate (January 2022) and at the end (January 2023) of the acquiring period (13/02/20 to 29/03/22)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |
| | 2.1.1 Carbon storage and sequestration in vegetation per unit area per unit time | Sequestered $CO_2$eq by trees and shrubs in 2023:<br><br>2.64 ± 0.21 tonnes $year^{-1}$ $hectare^{-1}$<br><br>Sequestered $CO_2$eq by the trees and shrubs at full growth:<br><br>8.76 ± 1.06 tonnes $year^{-1}$ $hectare^{-1}$ | Modelled by *i-Tree Eco* at 2023 and at full growth (20 years) for trees and shrubs, by considering the individuals alive in May 2023 and the full NBS area of 1200 sqm.<br><br>2023 (trees and shrubs)<br><br>Carbon stored:<br>0.060 ± 0.006 tonnes<br>$CO_2$eq:<br>0.210 ± 0.021 tonnes<br><br>Carbon sequestered: |

| | | | | |
|---|---|---|---|---|
| | | | | 0.090 ± 0.007 tonnes/year<br>$CO_2$eq:<br>0.32 ± 0.03 tonnes/year<br><br>Full-growth (trees+ shrubs)<br><br>Carbon stored:<br>167± 34 tonnes<br>$CO_2$eq:<br>612± 123 tonnes<br><br>Carbon sequestered:<br>0.3 ± 0.03 tonnes/year<br>$CO_2$eq:<br>1.05 ± 0.13 tonnes/year<br><br>Uncertainty is Standard Deviation |
| | 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | PRE: 98 ± 27<br>POST 2021: 119 ± 24<br>POST 2022: 84 ± 22 | Mean (SD) number of visitors per day at pre- and post-implementation of the NBS (SOPARC) |
| | | 8.31.3 Number of and reasons for visits to an NBS area | 5 ± 22 visits per month<br>58% walking, 8% cycling, 8% running | Median (IQR) number of visits to NBS area and main activity (N=65) |
| | 5. Biodiversity Enhancement<br><br>(but also related to 4. Green Space Management) | 10.15 Equivalent used soil (A) | 2647 tonnes | This value may correspond to an equivalent amount of saved fertile soil from conventional agricultural fields |
| | 6. Air Quality | 12.1 Removal of atmospheric pollutants by vegetation | 2023 (trees and shrubs)<br>$O_3$: -280 ± 30 g/year<br>$NO_2$: -110 ± 11g/year<br>$SO_2$: - 31 ± 3 g/year<br>$PM_{10}$: - 85 ± 9 g/year<br><br>At full growth (trees and shrubs)<br>$O_3$:<br>- 32800 ± 4700 g/year<br>$NO_2$:<br>-114900 ± 2220 g/year<br>$SO_2$: - 3500 ± 500 g/year<br>$PM_{10}$:<br>- 15300 ± 2400 g/year | Modelled by *i-Tree Eco* at 2023 and at full growth (after 20 years) based on the trees and shrubs alive in May 2023<br><br>Uncertainty is Standard Deviation |

| | | | | |
|---|---|---|---|---|
| | | 12.2 Total particulate matter (PM) removed by NBS vegetation | 1.26 ± 0.15 g/day, considering only the trees alive in May 2023 and the following mean removed $PM_{10}$ daily load by trees:<br><br>• 1.8 ± 0.5 ug/cm$^2$ for *C. australis*<br>• 1.4 ± 0.3 ug/cm$^2$ for *M. 'Evereste'*<br>• 1.1 ± 0.3 ug/cm$^2$ for *Q. ilex* | Daily loads obtained by averaging results from leaves sampled in 10/07/2020 and 12/07/22; for both sampling dates, the last rain event occurred 7 days before<br><br>Uncertainty is Standard Error |
| | | Modelled NOx and PM in gaseous releases along the NBS lifecycle<br><br>Adapted from 12.4 (A) | Fine particulate matter formation potential:<br>94.9 kg $PM_{2.5}$ eq. per 1200 sqm. of NBS, after 3 years<br><br>Photochemical oxidant formation potential:<br>166.3 kg $NO_x$ eq. per 1200 sqm. of NBS, after 3 years | Total amount of potentially generated impact after three years of NBS lifetime (considering upstream, implementation and management phases) |
| | | Modelled trends in emissions of $NO_X$ and $SO_X$<br><br>Adapted from 12.6 (A) | Terrestrial acidification potential:<br>263.1 kg $SO_2$ eq. per 1200 sqm. of NBS, after 3 years | Total amount of potentially generated impact after three years of NBS lifetime (considering upstream, implementation and management phases |
| | | 12.7 Concentration of particulate matter (PM10 and PM2.5), $NO_2$, and $O_3$ in ambient air | $O_3$ in NBS (ppb):<br>59.7 ±2.3,<br>61.9 ± 2.5,<br>80.0 ± 15.1<br><br>$O_3$ in control site (ppb):<br>59.4 ± 4.3,<br>57.6 ± 3.7,<br>78.5 ± 9.0<br><br>$NO_2$ in NBS (ppb):<br>13.2 ± 0.2,<br>8.9 ± 0.3,<br>9.4 ± 0.3<br><br>$NO_2$ in control site (ppb):<br>15.3 ± 0.5<br>11.1 ± 0.5<br>12.3 ± 0.2 | Sampling periods: 14/06/2019 to 03/07/2019, 02/07/2021 to 22/07/2021 and 29/07/2022 to 19/08/2022<br><br>No statistically significant difference between NBS and control sites for $O_3$<br><br>Lower $NO_2$ concentration in NBS every year<br><br>Uncertainty is Standard Error |
| | 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | 18.5% | 18.5% of respondents declared that they had social interactions |

| | | | |
|---|---|---|---|
| | 20.4.2. Perceived social support | 13.4 | the total score of perceived social support was high (max score = 24) |
| | 20.5. Perceived social cohesion | 41,5% “not a lot” | The majority of respondents (41.5%) declared that perceived social cohesion among neighbours was increased “not a lot” |
| 11. Health and well-being | 22.1 Self-reported Physical activity | Walking: 64 ± 34 min<br>Moderate: 77 ± 43 min<br>Vigorous: 53 ±25 min | Average time (mean ± SD) performing the activity level on the days in which the activity was performed (N=65) |
| | 22.2 Observed physical activity levels within NBS | PRE:<br>sedentary: 16<br>walking: 52<br>vigorous:28<br><br>POST 2021:<br>sedentary: 26<br>walking: 51<br>vigorous: 33<br><br>POST 2022:<br>sedentary: 13<br>walking: 18<br>vigorous: 15 | Average number of visitors per day counted at pre and post-implementation of the NBS (SOPARC) |
| | 22.13. Perceived restorativenes s of NBS | 31.7 | the total score of perceived restorativeness was high (max score = 45) |
| 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created (R) | • 15 persons involved in co-design/planning<br>• new jobs in maintenance not yet quantifiable | new jobs will depend on the New soil commercialization |
| | 24.5 NBS cost/benefit analysis: Initial costs | 15 €/m³ | only new soil production |
| | 24.6 NBS cost/benefit analysis: Maintenance costs | | No data available |

| | | | | |
|---|---|---|---|---|
| | | Number of beneficiaries | Many | Not quantifiable since it is not recorded how many benefit (public, frequently used/passed areas) |
| | | Financial revenues | Not quantifiable | Significant revenues for the company are expected, upon New Soil commercialisation, not yet quantifiable |

**Table 10.** Turin NBS3.2: Gardens in Cascina Piemonte (Orti Generali), related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS3.2: Gardens in Cascina Piemonte (Orti Generali)** | 1. Climate Resilience | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | $DeltaT_{max}$ (July 2020) 1.10 ± 4.63 °C<br><br>$DeltaT_{max}$ (July 2021) 2.01 ± 3.45 °C<br><br>$DeltaT_{max}$ (July 2022) 1.49 ± 3.45 °C | Monthly mean of daily maximum temperature of NBS site minus the monthly mean of daily maximum temperature at control site at beginning (July 2020), at intermediate (July 2021) and at the end (July 2022) of the acquiring period (13/02/20 to 29/03/23)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |
| | | Mitigation of daily minimum temperature<br><br>Adapted from 1.4 (R) | $DeltaT_{min}$ (January 2021) 0.04 ± 2.78 °C<br><br>$DeltaT_{min}$ (January 2022) 1.28 ± 2.65 °C<br><br>$DeltaT_{min}$ (January 2023) -0.81 ± 5.56 °C | Monthly mean of daily minimum temperature of NBS site minus the monthly mean of daily minimum temperature at control site at beginning (January 2021), at intermediate (January 2022) and at the end (January 2023) of the acquiring period (13/02/20 to 29/03/23)<br><br>No statistical difference |

| | | | |
|---|---|---|---|
| | | | Uncertainty is Standard Deviation |
| 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | POST 2019: 139 ± 70<br>POST 2021: 89 ± 40 | Mean (SD) number of visitors per day at post-implementation of the NBS (SOPARC) |
| | 8.31.3 Number of and reasons for visits to an NBS area | 9 ± 17 visits per month<br>64% gardening, 13% socializing | Median (IQR) number of visits to NBS area and main activity (N=90) |
| 5. Biodiversity Enhancement | 9.4 Species diversity within defined area per Shannon Diversity Index (R) | Shannon Diversity Index of butterflies at the species level:<br>2018: 1.835 (mean 1.52)<br>2019: 2.328 (mean 1.78)<br>2020: 1.966 (mean 1.44)<br>2021: 20.28 (mean 1.46)<br><br>Shannon Diversity Index of bees at the species level:<br>2019: 0.983 (mean 0.72)<br>2020: 1.743 (mean 1.25)<br>2021: 1.850 (mean 1.51) | Acquired continuously from 2018 to 2021 (april-september, except for COVID-19 lockdown period in 2020), for both butterflies and bees<br><br>For bees, the index was calculated from 2019 to 2021 due to the low number of recorded species of 2018 |
| | 9.5 Number of species within defined area per Evenness Index (R) | Shannon Evenness Index of butterflies at the species level:<br>2018: 0.623 (mean 0.68)<br>2019: 0.691 (mean 0.78)<br>2020: 0.636 (mean 0.23)<br>2021: 1.260 (mean 0.70)<br><br>Shannon Evenness Index of bees at the species level:<br>2019: 0.548 (mean 0.60)<br>2020: 0.572 (mean 0.72)<br>2021: 0.561 (mean 0.68) | Acquired continuously from 2018 to 2021 (april-september, except for COVID-19 lockdown period in 2020*), for both butterflies and bees. For bees, the index was calculated from 2019 to 2021 due to the low number of recorded species of 2018 |
| 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Not upscaled at the NBS level since very few trees are present<br><br>Mean removed $PM_{10}$ daily load by trees are:<br>• 1.1 ± 0.4 ug/cm$^2$for *M. domestica*<br>• 0.70 ± 0.02 ug/cm$^2$ for *M. nigra*<br>• 1.0 ± 0.2 ug/cm$^2$ for *Prunus spp.* | Daily loads obtained by leaves sampled in 10/07/2020; the last rain event occurred 7 days before<br><br>Uncertainty is Standard Error |

| | | | |
|---|---|---|---|
| | 12.7 Concentration of particulate matter (PM10 and PM2.5), $NO_2$, and $O_3$ in ambient air | $O_3$ in NBS (ppb):<br>61.08 ± 5.36,<br>56.47 ± 1.88,<br>77.27 ± 11.88<br><br>$O_3$ in control site (ppb):<br>59.43 ± 4.34,<br>57.59 ± 3.72,<br>78.46 ±8.96<br><br>$NO_2$ in NBS (ppb):<br>14.32 ± 0.54,<br>10.49 ± 0.38,<br>10.15 ± 0.36<br><br>$NO_2$ in control site (ppb):<br>15.29 ± 0.53,<br>11.09 ± 0.50,<br>12.32 ± 0.25 | Sampling periods: 14/06/2019 to 03/07/2019, 02/07/2021 to 22/07/2021 and 29/07/2022 to 19/08/2022<br><br>No statistically significant difference between the control and the NBS for $O_3$<br><br>Lower $NO_2$ concentration in NBS in 2022<br><br>Uncertainty is Standard Error |
| 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | 78,9% | 78,9% of respondents declared that they had social interactions |
| | 20.4.2. Perceived social support | 16 | the total score of perceived social support was high (max score = 24) |
| | 20.5. Perceived social cohesion | 32,2% “a little” | The majority of respondents (32.2%) declared that perceived social cohesion among neighbours was increased “a little” |
| 11. Health and well-being | 22.1 Self-reported Physical activity | Walking: 48.0 ± 54.132.0<br>Moderate: 147.3 ± 166.2<br>Vigorous: 90 ± 192.6 | Mean (SD) of minutes per week spent in the activity level (N=90) |
| | 22.2 Observed physical activity levels within NBS | POST 2019:<br>sedentary: 33<br>walking: 39<br>vigorous: 55<br><br>POST 2021:<br>sedentary: 14<br>walking: 34<br>vigorous: 33 | Average number of visitors per day counted at post-implementation of the NBS (SOPARC) |
| | 22.13. Perceived restorativeness of NBS | 33,7 | the total score of perceived restorativeness was high (max score = 45) |

| | | | | |
|---|---|---|---|---|
| | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created (R) | • 20 persons in NBS planning, co-design, implementation (different entities)<br>• 3 FTE in the maintenance/evolution | |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 508600 € | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | 163000 €/year | |
| | | 24.34 Value of food produced in NBS | 59000 kg/year | the food product will increase due to the incoming creation of new vegetable gardens planned for year 2024 |
| | | Number of beneficiaries | 500 | |
| | | Financial revenues | 159000 €/year | Without any funding |

**Table 11.** Turin NBS5.2: Green wall indoor at school, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS5.2: Green wall indoor at school** | 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Mean removed $PM_{10}$ load<br><br>2021:<br>• 5.7 ± 0.3 ug/cm2 for *Calathea orbifolia*<br>• 6.0 ± 1.1 ug/cm2 for *Chamaedorea elegans*<br>• 5.1 ± 1.0 ug/cm2 for *Chlorophytum comosum*<br>• 3.5 ± 0.9 ug/cm2 for *Marantha leuconeura*<br>• 3.6 ± 0.7 ug/cm2 for *Pilea peperomioides* | $PM_{10}$ load on leaves sampled 18/10/2021 and 19/10/2022 have been compared<br><br>Uncertainty is Standard Error |

| | | | |
|---|---|---|---|
| | | 2022:<br>• 9.0 ± 2.2 ug/cm2 for *Calathea orbifolia*<br>• 10.9 ± 1.7 ug/cm2 for *Chamaedorea elegans*<br>• 13.0 ± 0.5 ug/cm2 for *Chlorophytum comosus*<br>• 3.6 ± 0.5 ug/cm2 for *Marantha leuconeura*<br>• 10.7 ± 3.5 ug/cm2 for *Pilea peperomioide* | |
| | 12.7 Concentration of particulate matter (PM10 and PM2.5), $NO_2$, and $O_3$ in ambient air | Pre (ppb)<br>$NO_2$ in NBS: 16.6, 14.6<br>$NO_2$ in control site:17.9<br>$NO_2$ outdoor: 11.8<br><br>Post (ppb)<br>$NO_2$ in NBS: 16.0, 17.3<br>$NO_2$ in control site: 18.6<br>$NO_2$ outdoor: 13.0 | Sampling periods: pre NBS implementation 11/12/2020 to 18/12/2020,<br><br>post NBS implementation 22/01/2021 to 29/01/2021<br><br>No significant changes due to COVID-19 contrast measure (open windows all the time) |
| 8. Knowledge and Social Capacity Building for Sustainable Urban Transformation | Pro-environmental attitude | No observed changes | |
| | 15.4. Pro-environmental behaviour (R) | Increase observed in one class group over the four monitored | |
| 12. New Economic Opportunities and Green Jobs | 24.5 NBS cost/benefit analysis: Initial costs | 5279 € | |
| | 24.6 NBS cost/benefit analysis: Maintenance costs | 2400 €/year | |
| | Number of beneficiaries | 164 school pupils | |

**Table 12.** Turin NBS5.3: Green wall outdoor on a homeless dormitory, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS5.3: Green wall outdoor on a homeless dormitory** | 1. Climate Resilience | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | DeltaT$_{max}$ (August 2020) 2.1 ± 2.7 °C<br><br>DeltaT$_{max}$ (August 2021) 1.5 ± 3.4 °C | Difference (Tin -Tref) in the monthly mean of daily maximum temperature inside the building where the NBE is realized (Tin) and at a reference station (Tref), measured before (August 2020) and after (August 2021) the NBS installation (acquiring period: 05-26/08/2020 and 05/07/21 to 08/11/21)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |
| | | Mitigation of daily minimum temperature<br><br>Adapted from 1.4 (R) | DeltaT$_{min}$ (August 2020) 5.0 ± 2.3 °C<br><br>DeltaT$_{min}$ (August 2020) 4.5 ± 2.4 °C | Difference (Tin -Tref) in the monthly mean of daily minimum temperature inside the building where the NBS is realized (Tin) and at a reference station (Tref), measured before (August 2020) and after (August 2021) the NBS installation (acquiring period: 05-26/08/2020 and 05/07/21 to 08/11/2)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation |
| | 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Mean removed $PM_{10}$ daily load:<br><br>• 0.72 ± 0.08 ug/cm$^2$ for *Bergenia cordifolia*<br>• 0.24 ± 0.07 ug/cm$^2$ for *Carex flacca*<br>• 0.11 ± 0.02 ug/cm$^2$ for *Geranium cantabrigiense*<br>• 0.21 ± 0.03 ug/cm$^2$ for *Rosmarinus officinalis* | $PM_{10}$ daily load on leaves sampled 18/10/2021; the last rain event occurred 14 days before<br><br>Uncertainty is Standard Error |

| | | | | |
|---|---|---|---|---|
| | | | • 0.24 ± 0.01 ug/cm$^2$ for *Teucrium chamaedrys* | |
| | 12. New Economic Opportunities and Green Jobs | 24.5 NBS cost/benefit analysis: Initial costs | 21116 € | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | 9600 €/year | |
| | | Number of beneficiaries | beneficiaries at the homeless shelter: 70-85 per year | |

**Table 13.** Turin NBS5.4: New green roof at WOW, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS5.4: New green roof at WOW** | 1. Climate Resilience | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | $DeltaT_{max}$ (May 2020) 5.6 ± 5.9 °C<br><br>$DeltaT_{max}$ (May 2022) 0.9 ± 7.2°C | Monthly mean of daily maximum temperature of NBS site minus the monthly mean of daily maximum temperature at control site before (May 2020) and after (May 2022) the NBS installation (acquiring period: 13/02/20 to 29/03/23, May 2021 not available)<br><br>No statistical difference but tendency to decrease the difference (air temperature of the roof is mitigated)<br><br>Uncertainty is Standard Deviation<br><br>Not measured inside and outside since the building is not accessible |

| | | | | |
|---|---|---|---|---|
| | | Mitigation of daily minimum temperature<br><br>Adapted from 1.4 (R) | $DeltaT_{min}$ (March 2020) 0.7 ± 4.0°C<br><br>$DeltaT_{min}$ (March 2021) 0.8 ± 4.0 °C<br><br>$DeltaT_{min}$ (March 2022) 0.8 ± 4.9°C<br><br>$DeltaT_{min}$ (March 2023) 0.5 ± 5.5°C | Monthly mean of daily minimum temperature of NBS site minus the monthly mean of daily minimum temperature at control site before (March 2020) and after (March 2021, March 2022, March 2023) the NBS installation (acquiring period: 13/02/20 to 29/03/23)<br><br>No statistical difference<br><br>Uncertainty is Standard Deviation<br><br>Not measured inside and outside since the building is not accessible |
| | 6. Air Quality | 12.7 Concentration of particulate matter (PM10 and PM2.5), $NO_2$, and $O_3$ in ambient air | $O_3$ in NBS (ppb):<br>57.0 ± 1.6,<br>60.9 ± 1.2,<br>54.3 ± 7.9<br><br>$O_3$ in control site (ppb):<br>59.4 ± 4.3,<br>57.6 ± 3.7,<br>78.5 ± 9.0<br><br>$NO_2$ in NBS (ppb):<br>11.1 ± 0.4,<br>9.0 ± 0.2,<br>8.5 ± 0.1<br><br>$NO_2$ in control site (ppb):<br>15.3 ± 0.5<br>11.5 ± 0.5<br>12.3 ± 0.2 | Sampling periods: 14/06/2019 to 03/07/2019, 02/07/2021 to 22/07/2021 and 29/07/2022 to 19/08/2022<br><br>Lower $O_3$ concentration in NBS site in 2022<br><br>Lower $NO_2$ concentration in NBS site every year<br><br>Uncertainty is Standard Error |

**Table 14.** Turin NBS6.1: Green corridor, related societal challenges, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS6.1: Green corridor** | 4. Green Space Management | 8.31.2 Number of visitors in new recreational areas | PRE: 146 ± 15<br>POST: 86 ± 22 | Mean (SD) number of visitors per day at pre and post-implementation of the NBS (SOPARC) |

| | | | | |
|---|---|---|---|---|
| | 5. Biodiversity Enhancement | 9.4 Species diversity within defined area per Shannon Diversity Index (R) | Shannon Diversity Index of butterflies at the species level:<br>2021: 2.028 (mean 1.21)<br>2022: 1.729 (mean 0.45)<br>2023: 1.760 (mean 0.89) | Acquired continuously from 2020 to 2023 a least seven samplings were made in the period from March to September.<br>Due to the few species found, it was not possible to calculate the indices in 2020) |
| | | 9.5 Number of species within defined area per Shannon Evenness Index (R) | Shannon Evenness Index of butterflies at the species level:<br>2021: 0.590 (mean 0.73)<br>2022: 0.888 (mean 0.23)<br>2023: 0.609 (mean 0.38) | Acquired continuously from 2020 to 2023 a least seven samplings were made in the period from March to September.<br>Due to the few species found, it was not possible to calculate the indices in 2020) |
| | 11. Health and Well-being | 22.2 Observed physical activity levels within NBS | PRE:<br>sedentary: 22<br>walking: 13<br>vigorous: 95<br><br>POST:<br>sedentary: 17<br>walking: 13<br>vigorous: 56 | Average number of visitors per day counted at pre- and post-implementation of the NBS (SOPARC) |

**Table 15.** Turin NBS8: Butterfly gardens for disadvantaged people, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Turin NBS8: Butterfly gardens for disadvantaged people** | 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | Top 5 most relevant keywords identified are the following: “possibility”, “learn”, “colours”, “butterflies”, “study/work” | Standard version of the NBS visitor questionnaire cannot be applied to vulnerable users of NBS8. An alternative approach has been instead used, based on keyword cloud representation |
| | | 20.4.2. Perceived social support | | |
| | | 20.5. Perceived social cohesion | | |

| | | | | |
|---|---|---|---|---|
| | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created | • 20 persons involved in NBS planning, co-design, implementation<br>• no FTE in maintenance | |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 22000 € | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | <50 €/year | |
| | | Number of beneficiaries | 100 | |

## 3.4. NBS implementations monitored in the Zagreb Living Lab

**Table 16.** Zagreb NBS3.1: Sesvete City Garden – upgrading and new garden, related societal challenges and key performance indicators (KPIs). No substantial changes in the garden structure. The PM removal by the plant species most present was assessed to be compared with similar data in other NBS implementation.

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Zagreb NBS3.1: Sesvete City Garden – upgrading and new garden** | 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Not upscaled at the NBS level since very few trees are present<br><br>Mean removed $PM_{10}$ daily load by *J. regia* is:<br>• 0.26 ± 0.06 ug/cm$^2$ | Mean daily $PM_{10}$ load by averaging those obtained from leaves sampled in 26/08/20 and 09/10/22 (the last heavy rain event, i.e., >6.5mm/h, occurred on 06/08/2020 and on 16/09/2022):<br>• 0.39 ± 0.04 ug/cm$^2$ in 2020<br>• 0.12 ± 0.01 ug/cm$^2$ in 2022<br><br>Uncertainty is Standard Error |

**Table 17.** Zagreb NBS3.2: Sesvete City Garden –Therapeutic Garden, related societal challenges and key performance indicators (KPIs). The planned monitoring of type and frequency of use and of air quality and temperature has been discarded due to problems in data acquisition.

<table>
<tr><th>FRC, NBS type and title</th><th>Societal challenges</th><th>KPIs</th><th>Values</th><th>Comment</th></tr>
<tr><td rowspan="8">Zagreb NBS3.2: Sesvete City Garden – Therapeutic Garden</td><td>6. Air Quality</td><td>12.2 Total particulate matter (PM) removed by NBS vegetation</td><td>Not upscaled at the NBS level since very few trees are present<br><br>Mean removed $PM_{10}$ daily load by J. regia is:<br>• 0.14 ± 0.01 $ug/cm^2$</td><td>Mean daily $PM_{10}$ load by averaging those obtained from leaves sampled in 26/08/20 and 09/10/22 (the last heavy rain event, i.e., >6.5mm/h, occurred on 06/08/2020 and on 16/09/2022):<br>• 0.15 ± 0.01 $ug/cm^2$ in 2020<br>• 0.12 ± 0.01 $ug/cm^2$ in 2022<br><br>Uncertainty is Standard Error</td></tr>
<tr><td rowspan="3">10. Social Justice and Social Cohesion</td><td>20.2 Perceived social interaction</td><td rowspan="3">Top 5 most relevant keywords identified are the following: “socializing”, “happiness”, “fun”, “fresh”, “rest”</td><td rowspan="3">Standard version of the NBS visitor questionnaire cannot be applied to vulnerable users of NBS8. An alternative approach has been instead used, based on keyword cloud representation</td></tr>
<tr><td>20.4.2. Perceived social support</td></tr>
<tr><td>20.5. Perceived social cohesion</td></tr>
<tr><td rowspan="4">12. New Economic Opportunities and Green Jobs</td><td>23.3 Direct economic activity: Number of new jobs created (R)</td><td>• 15 persons involved in NBS planning, co-design, implementation<br>• no FTE in maintenance</td><td></td></tr>
<tr><td>24.5 NBS cost/benefit analysis: Initial costs</td><td>376000 €</td><td>Mainly for physical implementation 280000 €, but also additional costs for water access, pre-construction costs, architect</td></tr>
<tr><td>24.6 NBS cost/benefit analysis: Maintenance costs</td><td>13000 €/year</td><td></td></tr>
<tr><td>Number of beneficiaries</td><td>50</td><td></td></tr>
</table>

**Table 18.** Zagreb NBS 4/5: Green Roof/Photovoltaic cells/Green wall & Aquaponics testing installation, related societal challenges and key performance indicators (KPIs).

| FRC, NBS type and title | Societal challenges | KPIs | Values | Comment |
|---|---|---|---|---|
| **Zagreb NBS 4/5: Green Roof/Photovoltaic cells/Green wall & Aquaponics testing installation** | 1. Climate Resilience | Mitigation of daily maximum temperature<br><br>Adapted from 1.3 (R) | $DeltaT_{max}$ (July 2022) -8.1 ± 4.5 °C<br><br>$DeltaT_{max}$ (July 2023) -7.5 ± 4.2 °C | Difference (Tin-Tref) in the monthly mean of daily maximum temperature inside the building where the NBS is located (Tin) and at a reference station (Tref), measured at beginning (July 2022) and at the end (July 2023) of the acquiring period (15/07/22 to 21/07/23)<br><br>Delta $T_{max}$ decreases in 2023, likely because biomass on the root and in the wall are much less<br><br>Uncertainty is Standard Deviation |
| | | Mitigation of daily minimum temperature Adapted from 1.4 (R) | $DeltaT_{min}$ (January 2023) 4.8 ± 3.8 °C | Difference (Tin-Tref) in the monthly mean of daily minimum temperature inside the building where the NBS is located (Tin) and at a reference station (Tref), measured in January 2023; acquiring period: 14/07/22 to 21/07/23<br><br>Uncertainty is Standard Deviation |
| | 6. Air Quality | 12.2 Total particulate matter (PM) removed by NBS vegetation | Mean removed $PM_{10}$ load by the plants present in the NBS:<br><br>• 0.31 ± 0.07 ug/cm$^2$ for *Allium schoenoprasum*<br>• 1.00 ± 0.43 ug/cm$^2$ for *Ocimum basilicum*<br>• 0.40 ± 0.05 ug/cm$^2$ for *Origanum*<br>• 0.78 ± 0.20 ug/cm$^2$ for *Salvia officinalis*<br>• 1.2 ± 0.2 ug/cm$^2$ for *Thymus vulgaris* | $PM_{10}$ daily load on leaves sampled 13/09/2021, 15 days from the last rain event<br><br>Uncertainty is Standard Error |

| | | | | |
|---|---|---|---|---|
| | 10. Social Justice and Social Cohesion | 20.2 Perceived social interaction | 100% | 100% of respondents declared that they had social interaction<br>Only 4 participants |
| | | 20.4.2. Perceived social support | 17 | The total score of perceived social support was high (max score = 24)<br>Only 4 participants |
| | | 20.5. Perceived social cohesion | 50% "a little" | Majority of respondents (50%) declared that perceived social cohesion was improved "a little"<br>Only 4 participants |
| | 11. Health and well-being | 22.13. Perceived restorativeness of NBS | 30,8 | The total score was high (max score = 45)<br>Only 4 participants |
| | 12. New Economic Opportunities and Green Jobs | 23.3 Direct economic activity: Number of new jobs created (R) | • 1 person in planning /implementation<br>• 1 FTE in maintenance not yet quantifiable | When aquaponics will be running, 2 persons will be involved (FTE not yet quantifiable) |
| | | 24.5 NBS cost/benefit analysis: Initial costs | 150000 € | |
| | | 24.6 NBS cost/benefit analysis: Maintenance costs | not yet quantifiable | Aquaponics system is not running |
| | | Number of beneficiaries | 30 | Mainly other businesses willing to implement this kind of system (or similar) |
| | | Financial revenues | Marginal | It is a showcase for replication/upscaling by the company and externals; thus, only basis for significant financial revenues |

# 4. Benefits' assessment at the NBS level: success stories within proGIreg

Nature-based solution implemented during proGireg have been often realized to address specific local needs. As a consequence, as described in Chapter 3, their impact was mainly evaluable only in connection with few KPIs per implementation. However, thanks to the LL approach, several NBS implementations were realized within the same area. Thus, by grouping them into a single narrative, they have allowed the identification of success stories providing benefits in connection with multiple societal challenges at the same time, as stated in the UNEA5 definition of NBS[12].

An overview of the impact across SC is provided here for three selected success stories in proGIreg. A detailed description of data acquisition and analysis can be found in the D4.5[5] and in the related, cited, scientific publications. The full dataset is available on the proGIreg dataplatform ( **www.progiregdata.eu** ).

## 4.1. The regeneration of a former urban landfill

Abandoned landfills are a common element of post-industrial landscapes that can be transformed from environmental nuisance into elements of urban green infrastructure, through the NBS concept. Initially located on the periphery of cities, landfills have become more integrated into the urban fabric. This is extremely relevant if the different environmental risks associated to them are considered. Once safeness is ensured, landfills present a potential for being integrated into the urban green infrastructure as an intervention of NBS, thus being able to provide several ecosystem services (ESs).

The former Deusenberg landfill site located in Dortmund, in the Huckarde post-industrial district, has been recultivated since 1992, with a four-meter-thick isolation layer being applied to an area of around 54 hectares and up to 55 meters in height for future vegetation. About 150,000 trees have been planted for this purpose. The Deusenberg was named after the Deusen district and opened to the public in 2004. Since then, it has become a popular destination for various recreational activities such as (dog) walking, jogging, cycling, mountain biking, bird watching, etc. Access to the top of Deusenberg is mainly from the northeast side via several trails and stairs. Because of its uniqueness, recreational and spatial significance, the citizens of Huckarde have expressed their desire to local politicians to improve the connection of their settlements to the Deusenberg recreational area. Thus, the Deusenberg has been made accessible by proGIreg through the realization of a barrier-free path in the southeast side (NBS6: Connection Huckarde with renatured Emscher river and Deusenberg sites), which has been also implemented with pollinator-friendly plants. Indeed, the Deusenberg will become part of the exhibition area of the International Garden Exhibition in 2027. Furthermore, a photovoltaic plant has been realized on top of the site (NBS1.1: Integrating solar energy production on Deusenberg landfill). The coexistence of these three interventions (renaturalization, accessible corridor and photovoltaic plant) in the same site, boosted by the participatory process put into action, makes the Deusenberg landfill a perfect example of multifunctional NBS providing benefits for nature and humans.

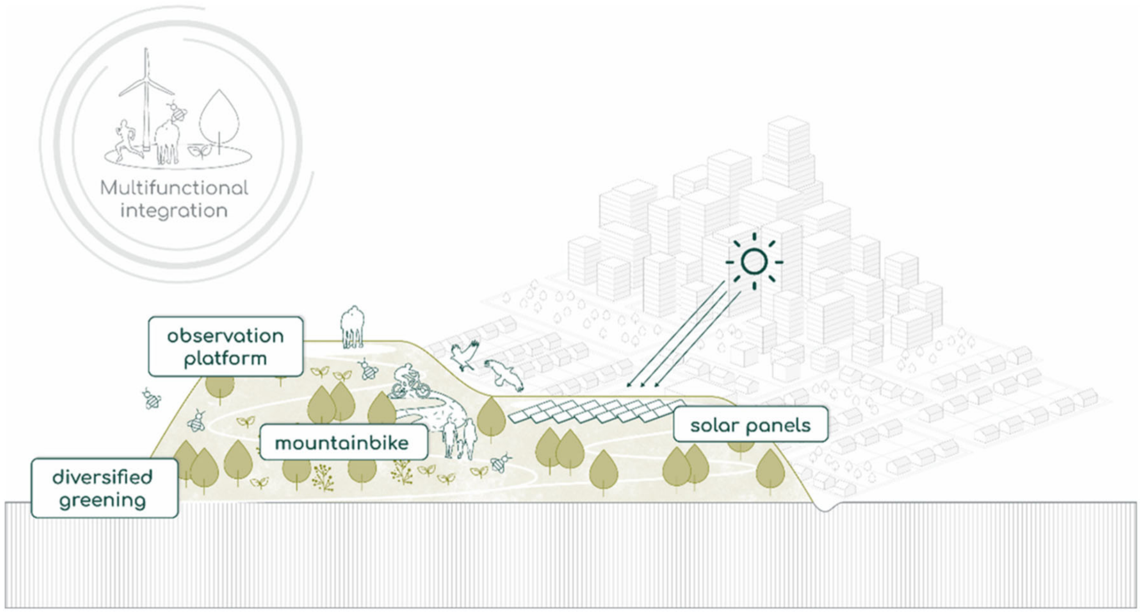



**Figure 5.** Different NBS and other measures combined to make the Deusenberg landfill a multifunctional green infrastructure: greening with trees and shrubs, accessibility of vistas by steps and walkways, a mountain biking parkours, solar panels and diversified greening for enhancing pollinator friendliness. (image © Ref.17).

### *Impact on nature and environment*

The renaturalization of a 54 hectars wide former landfill is expected to provide several environmental benefits, ranging from climate change mitigation (SC 1) and air quality improvement (SC 6) to biodiversity enhancement (SC 5), but also including aspects related to water management improvement and environmental risks mitigation (SC 2 and 3). Based on the expertise available among the local partners of the project consortium, the environmental impact of the renaturalization of the Deusenberg landfill has been evaluated only in connection with SC 1 and 6, through both experimental and modelling approaches.

In particular, the amount of PM removed per year has been experimentally evaluated through a quali-quantitative characterization of the PM particles deposited on the leaves of the different tree species present in the site by a well-established electron microscopy based procedure[16]. Leaf sampling was carried out in September 2019, from four different tree species, within this NBS: *Acer campestre* L., *Betula pendula* Roth, *Carpinus betulus* L. and *Salix alba* L.. Density, elemental composition, and weight of leaf deposited PM were assessed as a function of particle size fraction and tree species. $PM_{10}$ removal resulted in a maximum of 3.8 ± 0.4 µg $cm^{-2}$ of leaf unit area, detected for *S. alba* L. (Figure 6). The PM load experimental results, upscaled at the NBS level, correspond to a removal of 6.8 ± 1.3 and 14.9 ± 2.9 kg $ha^{-1}$ $year^{-1}$, respectively for $PM_{2.5}$ and $PM_{10}$.

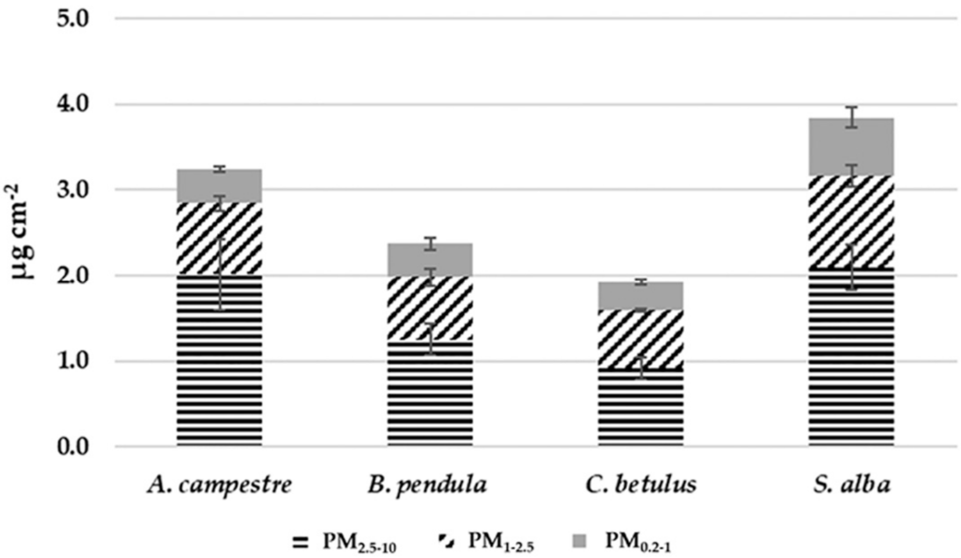



**Figure 6.** PM mass concentration on leaves (μg $cm^{-2}$), as obtained from SEM/EDX, through the combination of PM density and elemental composition results, as averaged values over the six leaves per each species. Standard deviations are given for each size fraction and each species (image @ Ref.17)

Furthermore, in 2020, the biometric and tree health status information of the planted trees has been collected to evaluate the species specific and the total amount of yearly removed air pollutants (including $CO_2$, other GHG, and PM) and stored carbon by using the *i-Tree Eco* model[15]. The results obtained show an annual removal 46.4 ± 10.7 kg $ha^{-1}$ of tropospheric $O_3$, 26.5 ± 6.0 kg $ha^{-1}$ of $NO_2$, 2.4 ± 0.6 kg $ha^{-1}$ of $SO_2$ and finally 3.4 ± 0.8 kg $ha^{-1}$ of $PM_{2.5}$. The carbon impact was evaluated through the modelling of carbon storage and carbon gross sequestration, thus resulting in a total dry biomass of 320 ± 81 tonnes $ha^{-1}$ and a carbon gross sequestration of 11.6 ± 2.2 tonnes $ha^{-1}$ $year^{-1}$, which correspond to the sequestration of 2298 ± 8 tonnes $year^{-1}$ of $CO_2$ equivalent ($CO_2$eq).

Interestingly, this case study provided the opportunity to compare experimental with modelled evaluation of $PM_{2.5}$ removal, providing insight into the details of the modelling approach that have been described in a scientific publication[17]. Furthermore, the availability of both experimental and modelled data on air quality amelioration, set the basis for the future evaluation of the health impact assessment (HIA) of this NBS intervention[18], in connection with Benefits for humans and the SC 11.

Thanks to the realization of NBS1.1, a further contribution to carbon mitigation is provided in terms of avoided $CO_2$ emission by the site. NBS1.1 (Figure 7) in Dortmund has been implemented on the Deusenderg since 2017 by a private energy company, ENTEGRO Photovoltaik-Systeme GmbH. The solar park on Deusenberg site belongs to the city of Dortmund but is managed and maintained by a private affiliated company called EDG, Entsorgung Dortmund GmbH (Waste management company). 12735 solar modules produce

[17] Ristorini, M. et al. (2023), Nature-based solutions in post-industrial sites: Integrated evaluation of atmospheric pollution abatement and carbon uptake in a German city, Urban Climate 50, 101579.
[18] Ezzati, M. et al. (2006) Comparative Quantification of Mortality and Burden of Disease Attributable to Selected Risk Factors, in Lopez, A.D. et al. (eds) Global Burden of Disease and Risk factors: The International Bank for Reconstruction and Development. The World Bank, 241-268.

the electricity, 61 inverters produce the AC voltage. The solar park has a capacity of 3952 kWp (3952 MWp) and produces around 3600000 kWh per year, thus avoiding 780000 $m^3$ of natural gas or about 780000 litres of heating oil[19]. According to the standard emission factor for Germany[20], this production saves up to 2246 tonnes/year $CO_2$eq.

It is worth noting that the average $CO_2$eq emission pro capita in Germany in 2018 was of about 10.3 tonnes/year [21]. Thus, the carbon sequestration of the renatured Deusen site in its whole, corresponding to 4544 tonnes/year $CO_2$eq, accounts for the $CO_2$eq emission of about 441 German citizens per year.

**Figure 7.** The solar park on Deusenberg site (image © www.entegro.eu) and the green corridor, before and after the proGIreg intervention (image © Mais Jafari).

### *Impact on humans*

Apart from the co-benefits derived to human health from the air quality mitigation, the NBS intervention realized in the Deusen site also provides direct benefits to humans in terms of economic (SC 12) and well-being impact (SC4 and 11).

NBS1.1, despite its overall high implementation cost of 2.6 M€, guarantees 320,000 €/year financial revenues (significant) and provided new jobs both during the co-design and implementation phase (20 persons working on it; mainly part-time) and during maintenance (ca. 0.3 FTE). The beneficiaries are many, but not quantifiable.

At the same time, the 115 m long path created in this NBS (NBS6, implemented by the City of Dortmund and maintained by its affiliated company EDG, Entsorgung Dortmund GmbH, Figure 8), which connects the former landfill site in Deusenberg with the River Emscher cycling route, provides a shorter access to the recreational areas on the Deusenberg for Huckarde citizens, increasing human well-being. The systematic observational assessment (i.e., the SOPARC[14]) of the visitors of this area gave insight in the usage of this NBS and is presented in Figure 8. Before implementation of the green path, few people visited this area because the previous path was hidden and because the site is located in an isolated area.

[19] https://www.entegro.eu/solarpark-deusenberg-ist-im-bau/
[20] https://www.covenantofmayors.eu/IMG/pdf/technical_annex_en.pdf
[21] OECD Regional Outlook - Country notes – Germany Progress in the net zero transition (2021), available at https://www.oecd.org/regional/RO2021%20Germany.pdf

After implementation of the green corridor, the number of users increased significantly (p=.002) with approximately 15 (SD=7.6) visitors more per day than before implementation. Visitors were mainly adults, and after implementation of the NBS a small increase in senior and teenage users was observed, though this was not statistically significant (p = .554). Most visitors used the area for walking (100% before and 82% after implementation), but after implementation of the corridor, also users started performing activities of vigorous intensity were observed (0% before and 16% after implementation).

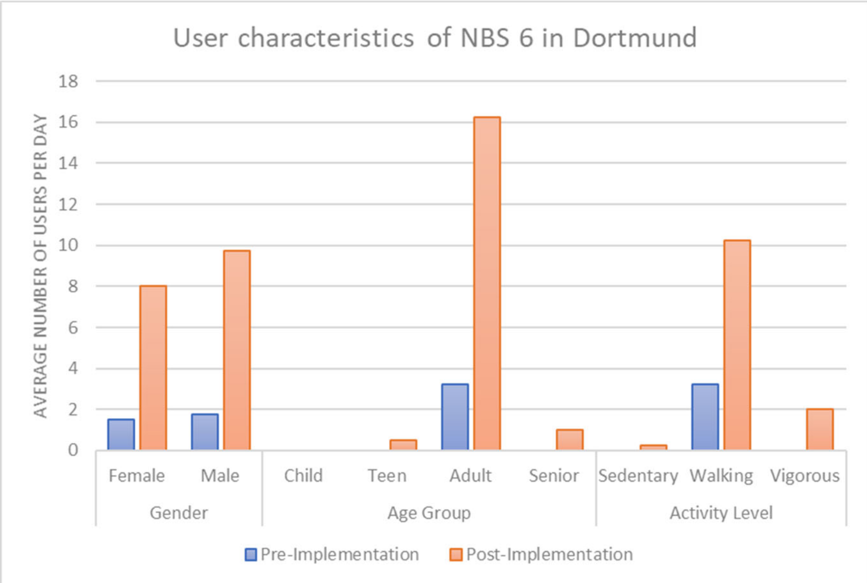



**Figure 8.** Number and characteristics of users at pre- and post-implementation of the NBS6 in Dortmund LL. Pre-implementation SOPARC assessment took place on 15, 17, 19 and 20 September 2020. Post-implementation SOPARC assessment took place on 21, 22, 24 and 25 March 2023.

## 4.2. New soil generation from urban waste and its use for the creation of new green urban areas

The local reuse of urban waste is a challenging task that can however reduce the environmental impact of both waste transport and treatment. The use of urban waste to generate new fertile soil, with low impact methods, that can then be reused in the same urban context to create and manage public green space instead of using fertile soil from the countryside, is thus an innovative NBS intervention fully inspired by the principles of transformative change and circular economy. The implementation of this NBS can be divided into two steps, each one providing specific benefits for humans and nature synergetically improving the overall impact.

In proGIreg, such NBS intervention has been put into action in Turin FRC (NBS2: New soil in Sangone Park), where regenerated soil based on excavated material with the addition of compost from organic fraction of municipal solid waste, zeolites and innovative biostimulants, has been used to realize an “urban forest” of 1200 sqm. along the banks of the Sangone river (Figure 9). Five tree species (*Celtis australis*, *Gleditsia triacanthos* ‘sunburst’, *Malus* x *evereste*, *Quercus ilex* and *Tilia cordata* ‘greenspire’) and five shrubs’ species (*Eleagnus ebbingeii*, *Physocarpus* ‘diable d’or’, *Spirea vanhouttei*, *Teucrium fruticans*, and *Ligustrum texanum*) were selected. Sixty trees and sixty shrubs have been planted in 2020 to test on their resilience. To test the quality of the new soil as well, a nearby control site of 300 sqm. with local soil has been used. Here, 3 plants for each selected tree and shrub species were also planted. With no watering addition, plants and shrubs grown on new soil were more resilient than the ones grown in the local soil. In particular, the 67% of the trees survived in the pilot while 53% survived in the control after 3 years (May 2023). The works for this NBS were coordinated by Environment Park SpA with the contribution of several partners: Dual Srl (realization of the construction site), UNITO and CNR (monitoring activity), ACEA (compost provider), CCS (biotic compound provider), City of Turin, Città Metropolitana di Torino, and the Regional Agency for the Protection of the Environment (ARPA) Piemonte (administrative procedures).

**Figure 9.** The new soil just arrived in the Sangone park (left) and the pilot after implementation (right) (image © City of Turin).

### *Impact on nature and environment*

The local reuse of urban waste in greenery is expected to provide, on a lifetime span, several environmental benefits, mainly related to climate change mitigation (SC 1) and air quality improvement (SC 6). The creation of new green areas may also have an impact on water management (SC 4) and biodiversity enhancement (SC 5). Since the new forest created as pilot test in Turin is very small and realized within an already green area, these aspects were not evaluated.

To consider the impact associated with the whole NBS lifetime, the environmental performance of the new soil production system and its deployment in the pilot case of Turin has been evaluated with the method of life cycle assessment (LCA). LCA is an ISO (14040 and 14044) standardized methodology well known in the field of industrial ecology for quantifying the environmental impacts associated with products supply-chain[22].

[22] Hauschild, M.Z., Rosenbaum, R.K., Olsen, S.I. (Eds.) (2018), Life Cycle Assessment - Theory and Practice. Springer International Publishing AG, Cham, Switzerland.

The model of the life cycle activities has been divided in four main parts (upstream, implementation, management and end-of-life, as shown in Figure 10). For all the life cycle phases, a specific inventory of energy and material flows in input and output has been performed, and the related environmental impacts have been calculated in connection with several environmental impact category indicators, potentially relevant for characterizing the environmental footprint of this NBS. Among those, the calculation of the impact due to the carbon footprint, terrestrial acidification, photochemical oxidation and PM formation associated with the NBS life cycle activities was considered particularly meaningful for proGIreg. On one hand, those indicators well represent the impact on human health. On the other hand, equivalent but opposite in sign indicators exist in ecosystem services assessment which can be used to compare and balance harmful and beneficial impacts.

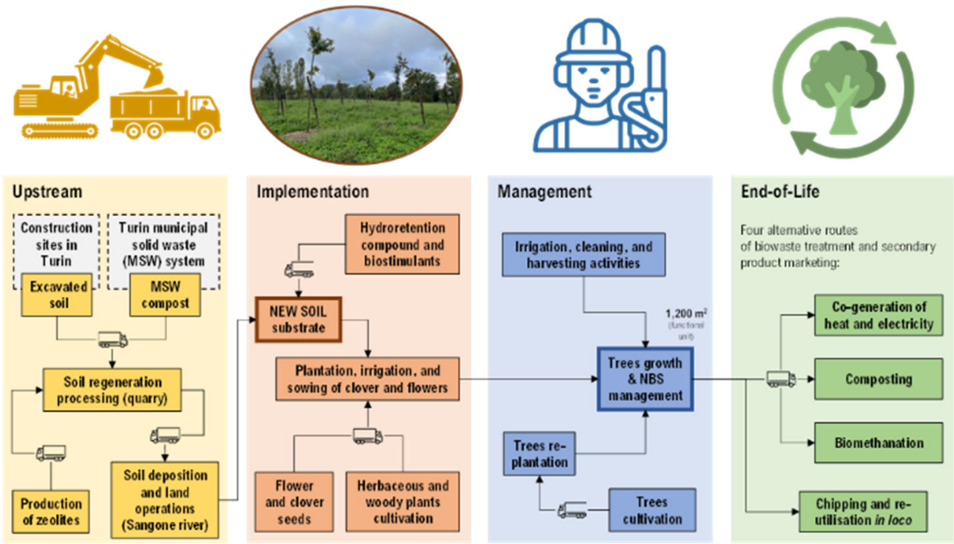



**Figure 10.** System boundary of the New Soil NbS life cycle model; activities within the dotted lines are excluded. Icons sourced by Flaticon (www.flaticon.com, accessed on 1 August 2023) (image @ Ref.23).

As shown in Figure 10, the NBS life cycle model also includes several end-of-life scenarios (up to 50 years), although the pilot has been implemented only three years ago. Those were defined to offer a prospect on the potential impact of the NBS over its whole lifetime in comparison with alternative strategies of waste and resource treatment. Such an ex-ante analysis follows an ex-post analysis developed instead to define a 'baseline' of the impacts possibly generated so far from the upstream, implementation and management phase after three years of NBS lifetime. Results of those analyses were settled in a research manuscript currently under review[23].

To give a preliminary hint on those results, it is worth mentioning that using 2647 tonnes of new soil to create the new urban forest in the Sangone park saved around 32 tonnes of $CO_2$eq, when compared to a business-as-usual scenario where fertile soil is harvested from agricultural fields and the waste inert soil from construction activities is landfilled. Despite this amount is not apparently very high, at least when considering that it may offset the annual

[23] Rugani, B. et al., Coupled life cycle assessment and business modelling to estimate the sustainability of soils regeneration for nature-based solutions. Submitted to Urban Forestry & Urban Greening in November 2023 (under review).

carbon footprint of only four Italian citizens, an up-scaling at broader urban or peri-urban land use contexts (e.g., 10, 100, or even 1000 ha of NBS land coverage) and economic-based analyses to balance with the ES provision may return meaningful positive impacts for the society and human well-being.

Indeed, the pilot test, thanks to the presence of trees and shrubs, ensures a positive impact in term of $CO_2$eq sequestration, which has been estimated by *i-Tree Eco* modelling[15] starting from real biometric data of the survived trees and shrubs. The $CO_2$eq sequestration is estimated to be about 0.32 ± 0.03 tonnes/year in 2023 (since the survived trees and shrubs are still very young) and it will be about 1.05 ± 0.13 tonnes/year at full growth (in 20 years). Furthermore, the regenerated soil itself has been turned into a carbon sink by the regeneration action, and this could be also evaluated.

The species specific and full intervention air pollutant removal has also been modelled by *i-Tree Eco*[15] and experimentally determined by SEM/EDX[17] (Figure 11), to further investigate which tree species provide more services and to obtain information on the overall air quality amelioration induced by the intervention. In particular, it has been estimated by *i-Tree Eco*[15] that the whole NBS intervention in 2023 (by considering only the survived plants, both trees and shrubs) has removed 280 ± 30 g/year of ozone, 110 ± 11 g/year of nitrogen dioxide, 31 ± 3 g/year of sulphur dioxide and 85 ± 9 g/year of $PM_{10}$, with *G. triacanthos* being the most efficient tree species and *T. cordata* the least once. The potential removal of the same pollutants at plant full growth has been also estimated (see Table 9).

The experimental assessment of the PM removal capacity of the tree species has been evaluated twice during the project, in 2020 and in 2022. By averaging the obtained results, the $PM_{10}$ daily load (mass per unit leaf area per day) of the following tree species have been obtained: 1.8 ± 0.5 ug/cm$^2$ for *C. australis,* 1.4 ± 0.3 ug/cm$^2$ for *M. 'Evereste' and* 1.1 ± 0.3 ug/cm$^2$ for *Q. ilex*. Thus, by considering the leaf area index of the survived trees in the park, it can be estimated that the 12 plants of *C. australis*, the 8 plants of *M. 'Evereste'* and the 7 plants of *Q. ilex* removed a total of 1.26 ± 0.15 g/day, which can be upscaled to about 300 g/year, by considering a vegetative period of eight months.

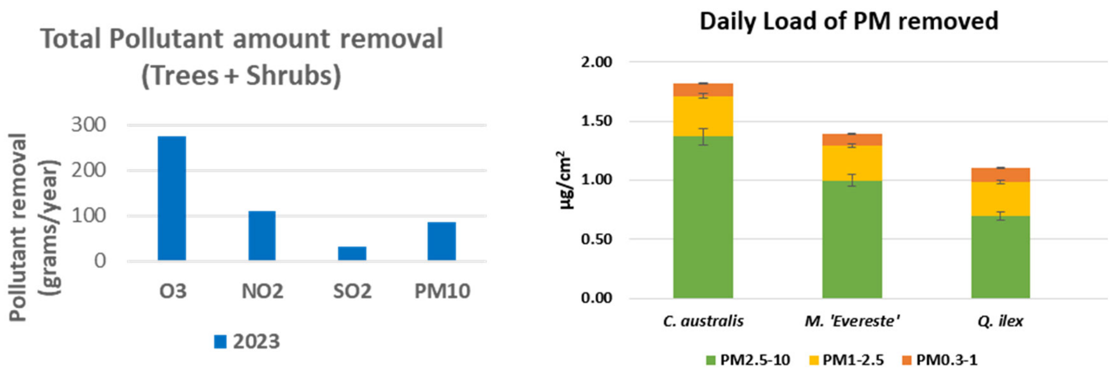



**Figure 11.** *I-Tree Eco* modelled air pollutant removal on 2023, based on real biometric data of trees and shrubs (left) and SEM/EDX experimentally determined daily PM size fractions removed per unit leaf area, per tree species (right) (image @CNR).

Concentration of pollutants in the atmosphere and air temperature have been also monitored along the project within the NBS site and compared with analogous measurements in a control site. No significant differences have been observed for air temperature and $O_3$ concentration along the project, between NBS and control sites. Instead, $NO_2$ concentration was significantly lower in the NBS site with respect to the control site. However, this was observed also before the NBS implementation, so it is no longer depending on it. This may be due to the implementation and plants' small size, but also to the lack of real-time monitoring which would have allowed for a more accurate identification of eventual differences over time and between the control and the NBS. This demonstrates the importance of setting the monitoring tool to the scale of the expected impact.

### *Impact on humans*

A quantitative HIA[18] is being finalized in order to estimate the avoided mortality and related health costs in Turin city as a consequence of improved air quality after implementation of the NBS. The improvement in air quality by the new vegetation have estimated by *i-Tree Eco*[15] in two different scenarios. A first scenario concerns the number of trees and shrubs in the NBS area that are currently present. A second scenario concerns the same combination of these types of trees and shrubs at a larger scale, to reach the recommended 50 $m^2$ of urban green space per capita[24]. Population data (mortality rate and city inhabitants) have been obtained from local population databases[11]. The response function between a change in air pollutants and the relative risk (RR) for all-cause mortality (obtained from meta-analysis) has been applied to estimate the relative risk and population-attributable fraction, enabling the assessment of premature deaths. Results will be made available after the end on the project.

Apart from the co-benefits derived to human health from the air quality mitigation, this NBS intervention also provides direct benefits to humans in terms of economic (SC 12), social (SC 4 and 10) and well-being impact (SC 11).

Being a newly developed technology, the new soil production had a significant implementation cost of 278,000€, but more significant revenues are expected in the future, still not quantifiable due to the novelty of the process development. During co-design and implementation, 15 persons worked on the realization. The continuous production of new soil will also have an impact in terms of new job creation, still not quantifiable since it will depend on the new soil demand. Furthermore, the implementation of this NBs led to the creation of a new enterprise: Dual Green. Similarly, the number of beneficiaries will depend on the future application of the new technology and of the new green area further realized, including public green parks resulting in a huge number of beneficiaries.

For instance, despite being located in an already green area, the pilot test in Sangone park has a positive impact on both social and well-being aspects. Systematic observation in the area (i.e., by SOPARC[14]) and interviews with visitors (i.e., the NBS visitor questionnaire) gave insight into the usage of the area. 18% of the interviewed visitors reported to visit the site more often after implementation of the NBS than before, although on-site observations

[24] Russo, A. et al. (2018), Modern Compact Cities: How Much Greenery Do We Need?, Int. J. Environ. Res. Public Health 15, 2180.

did not demonstrate a higher number of visitors post-implementation (see Figure 12, top). Interestingly, more children are now visiting the park than before the implementation of the NBS, and this difference in the age group is statistically significant ($p < .001$). Visit intensity was highest for seniors, with an average of 6 more visits per month and 34 minutes longer stay as compared to adults. Most visitors are male (62%) and well-educated (74%). A variety of activities are performed in the park. In decreasing occurrence, these are: walking, walking the dog, running, cycling, socializing, and quiet activities such as reading and relaxing. Some visitors reported to have experienced sunburn (5%), allergic reaction (2%), or an accident (2%) on the site. Nevertheless, the perceived restorativeness and social interaction among the visitors increased (32 ± 7 / 45 and 14 ± 5 / 24, respectively). This might be due to the visitors' positive perceptions of the quality of the NBS area (Figure 12, bottom). Visitors especially appreciated the views, sounds, colours and experienced connection with nature (i.e., sensory perception) while being in this new green urban area.

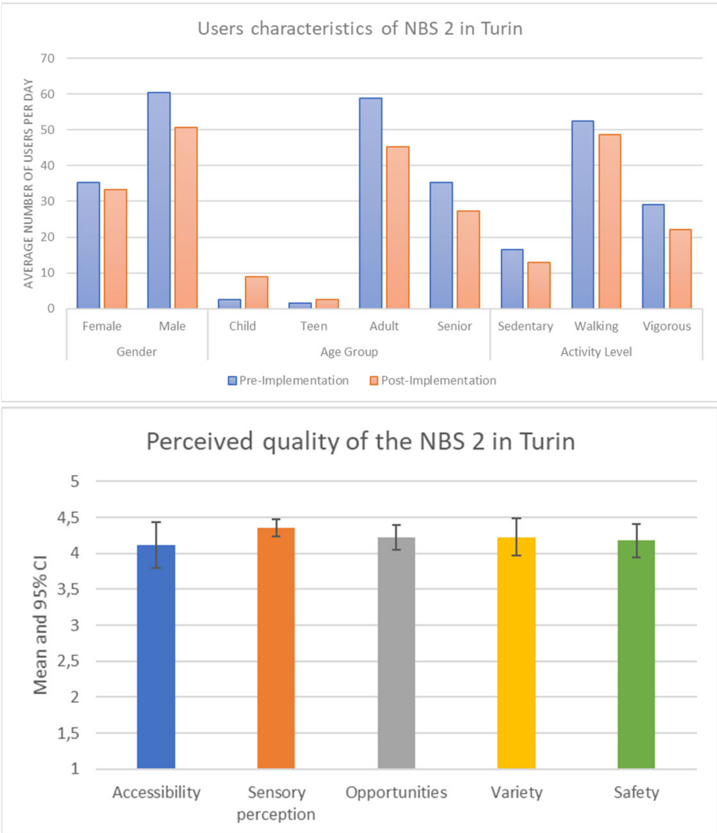



**Figure 12.** Top: Number and characteristics of users at pre- and post-implementation of the NBS2 in Turin LL. Pre-implementation SOPARC assessment took place on 26 September and 1, 3 and 4 October 2019. Post-implementation SOPARC assessment took place on 26-27 September and 2 and 8 October 2022. Bottom: Perceived quality of NBS2 in Turin LL (scale 1-5) (N=65). (image @ISGlobal).

## 4.3. The regeneration of an urban lake

Urban lakes are crucial part of the blue and green urban infrastructure, providing essential benefits to humans and biodiversity. However, they often suffer of maintenance problems and related pollution, which impact the water quality and, hence, the lake ecosystem and related services. In recent years, The Moon Lake in Ningbo (China, Figure 13) suffered of severe eutrophication events, and seasonal polluted and malodorous water has appeared in parts of the lake. The water quality has gradually deteriorated, greatly reducing the ecological and social benefits of the urban lake. Thanks to a joint action of local authorities and research institutions (represented by the model of governance put into action by NBS7: Procedures for environmental compensation), an NBS intervention has been implemented to restore the lake ecosystem, consisting in the planting of aquatic plants along the shore of the lake (NBS3: Planting aquatic plants along the shore of the lake).

The environmental compensation procedure in Ningbo is actually the operation process of the PPP (public-private-partnership) model: the local government (the government of Haishu District) has signed a PPP agreement with private enterprise (Tianhe Aquatic Ecosystems Engineering Co.Ltd) to treat the Moon Lake Park. In the agreement, the governance and maintenance period of the project is ten years. The local government pays compensation to the private enterprise in 8 instalments, for a total of 750000 euros, based on performance control performed by a public research institution (IUE-CAS). The assessment is divided into two aspects: water quality and greening quality. In terms of water quality, the private enterprise can successfully receive the government compensation if the water quality reaches target values of the China Surface Water Environmental Quality Standard (GB 3838-2002)[25]: (1) The main water quality index assessment is better than Class IV (i.e., potassium permanganate index ≤ 10, $NH_3$-N ≤1.5mg/L, TP≤0.1mg/L); (2) two years after the end of the project renovation period, the main water quality indicators have reached Class III (i.e., potassium permanganate index ≤ 6, NH3-N≤ 1.0mg/L, and TP ≤ 0.05mg/L). In terms of greening quality, the assessment includes landscape effects, plant maintenance, pest control, water and land sanitation management, garden landscape lights, railings, and other facilities maintenance. For each item, specific scoring standards have been developed.

So far, the private enterprise has been able to receive compensation in each phase. This is a successful case of interplay among new model of governance and restoration actions, which allowed to obtain positive impact in terms of benefits for humans and nature. This makes the Ningbo NBS intervention a good example of virtuous synergies among stakeholders.

The effectiveness of this NBS has been evaluated in connection with several ESs, and related indicators have been quantified, providing a multidisciplinary and multidomain description of the provided benefits. Moon Lake Park covers a total of 28 hectares, with the water area of Moon Lake itself occupying 9 hectares. This NBS consists in using macrophytes to renature a 5 km corridor surrounding the Moon Lake, to limit the runoff from non-point pollution sources in urban space. Due to variations in the characteristics of the lake's shoreline, some areas of the lake bottom are too deep for direct planting of aquatic

[25] According to China's Surface Water Environmental Quality Standard (GB 3838-2002), water having TN≤1.5 mg/L, TP≤0.1 mg/L, and NH3-N≤1.5 mg/L is classified as Class IV and it is mainly suitable for general industrial water areas and recreational water areas where the human body is not directly contacted, while water having TN≤1 mg/L, TP≤0.05 mg/L, NH3-N≤1 mg/L is in Class III and it is mainly suitable for centralized domestic and drinking water surface water source areas, secondary protection areas, fish and shrimp wintering grounds, migration channels, aquaculture areas and other fishery waters and swimming areas.

plants. Therefore, approximately 500 ecological planting boxes (100 x 60 x 50 cm) have been installed, covering about 1700 $m^2$. Each box hosts 6 plants, for a total of about 3000 aquatic plants, including include iris, canna, calamus and pontederia. These plants can not only reduce water pollutants' concentration (removing heavy metals and other serious contaminants) or eutrophication (by removing nutrients), but also increase the beauty and ornamentation of Moon Lake Park, which can attract more tourists.


**Figure 13.** The Moon Lake with indicated the water sampling point (left), the used boxes (central-left), the management of the newly planted aquatic plants (central right), and the water sample collection (right) (images © IUE-CAS).

### *Impact on nature and environment*

The main impact on nature and environment expected from this NBS concerns the improvement of the Moon Lake water quality (SC 2), thanks to the uptake of contaminants present in the water by the installed aquatic plants. As a consequence, also the biodiversity of the lake should be improved (SC 5). However, even if the leaf area of the single plant is small, the high number of plants and the extension of the intervention may deserve an interest also in connection with air quality mitigation (SC 6) and carbon impact (SC 1). All these aspects have been at least partially evaluated, included the role of the plants in pollutants uptake, also to set the stage for future investigations.

The total phosphorus (TP), total nitrogen (TN), ammonia nitrogen ($NH_3$-N), chlorophyll-a (Chl-a), and total suspended solids (TSS) contents of the Moon Lake water has been measured from samples collected at three sampling points (S1 water inlet, S2 lake centre, and S3 water outlet, Figure 14) from January 2019 to December 2021 (Figure 11). These three sampling points can effectively represent the overall condition of the lake water quality. Firstly, their locations are widely dispersed. Secondly, the water entering the lake at the inlet (S1) is purified after going through the purification system, making it relatively clean. The water quality at the central point (S2) is more representative of the general situation, and the outlet (S3) is located farther from the central point. Although the lake's water flow is relatively slow, the water flows from S1 to S2 and then to S3.

In 2019, TP and TN values were in the Class IV-V range. After the intervention, they reached Class IV water standards, and even Class III water standards in some periods, by the end of 2020. In 2019, the $NH_3$-N content at three sampling points was in the Class IV water standard, while after 2020, it has basically reached the Class III water standard. The relative content of the TSS index is generally declining from 2019 to 2021.

In 2019, the high levels of Chl-a revealed that Moon Lake's water quality was severely eutrophicated. Chl-a levels dramatically dropped in 2020, showing that the rate of eutrophication of Moon Lake's water quality has slowed down to some extent. In 2021, spring and winter had lower levels of Chl-a, with respect to summer and fall.

Overall, there is a slightly increased tendency in the eutrophication degree compared to 2020, but the water quality in terms of TP, TN, $NH_3$-N and TSS in 2020 and 2021 is much better than it was in 2019. When it comes to seasonality, Moon Lake's water quality is better in the spring and winter and poorer in the summer and fall, likely due to the intensification of human activity and the effects of extreme weather.

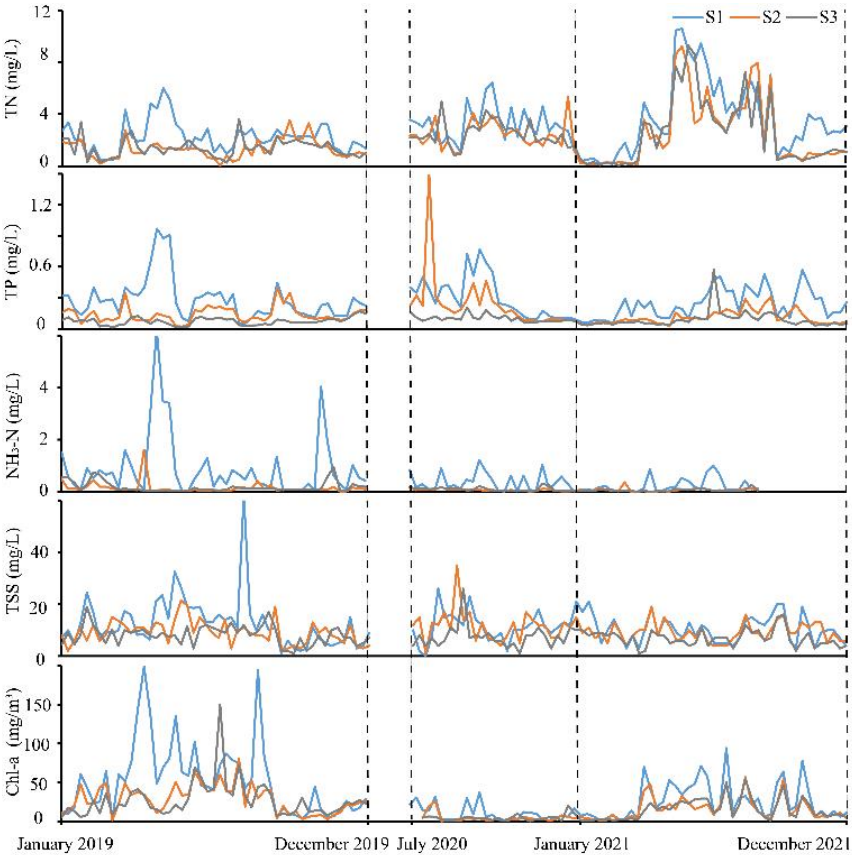



**Figure 14.** Total phosphorus (TP), total nitrogen (TN), ammonia nitrogen (NH3-N), total suspended solids (TSS) and chlorophyll-a (Chl-a) contents of the Moon Lake water samples collected at the three sampling points S1, S2, and S3 from January 2019 to December 2021. Sampling has been stopped during the first six months of 2020 due to the COVID-19 pandemic. (image © IUE-CAS).

The relative abundance of phytoplankton in S2 from 2019 to 2021 has been also evaluated (Figure 15). Zooplankton estimation was also planned[5], but due to the lack of expertise to test the samples, it was then abandoned.

*Chlorophyta* and *Bacillariophyta* are the main divisions in various seasons, accounting for 45.39% and 30.72% on average, followed by *Cryptophyta* and *Cyanophyta*. *Dinophyta* and

*Chrysophyta* accounted for 8.45%, 7.99%, 3.42% and 3.20%, respectively. *Euglenophyta* has the smallest share of only 0.83%. Other phytoplankton species are rare.

The relative abundance of phytoplankton changes with time. The most noticeable change is the increase in the relative abundance of *Chlorophyta* (green algae), particularly in 2021. In the three consecutive samplings, the relative abundance of the *Chlorophyta* exceeded 50% in almost all of them. Furthermore, it can be observed that there is a decreasing trend in the relative abundance of *Bacillariophyta* (diatomea) in 2021. This is also reflected by the decrease in biodiversity being observed according to the Shannon indexes reported in Table 8: Shannon diversity and evenness indexes decreased from 1.625 and 0.835 (in 2019) to 1.2604 and 0.648 (in 2021), respectively. An increase in the relative abundance of *Chlorophyta* and a decrease in the relative abundance of *Bacillariophyta* are typically indicative of environmental changes and precursors of eutrophication processes, and it could be necessary to take appropriate measures to restore the ecological balance. Indeed, for phytoplankton, it is not better to have more diversity, but it is most important to maintain the balance of the ecosystem. For example, in March-May 2018, a green algal bloom broke out in Moon Lake. During this period, the Shannon diversity index at the Moon Lake was high (1.696 ± 0.316), but the evenness index (0.528 ± 0.085) was low[26].

Thus, despite the obtained amelioration in the water quality and the absence of large-scale blooms since 2019, the ecological balance of the lake has not been fully restored. Additionally, as shown by the last panel (bottom) in Figure 15, the Shannon diversity index and the Shannon evenness index of phytoplankton at the phylum level had a significant trend with seasons from 2019 to 2021. This indicates that phytoplankton variations are not only affected by the overall water quality but also correlates with other factors, such as temperature and light, but likely also to human activities, and these relationships deserve to be further investigated to properly adapt the NBS intervention, and thus restore the lake ecological balance. This is a good example of how the implementation / monitoring /adaptation loop should work in NBS.

[26] Zhou,L.X. et al. (2019). Characteristics of spring green algae blooms and affecting factors in an urban lake, Moon Lake in Ningbo City, China. (in Chinese with Engligh abstract). Journal of Lake Science, 31, 1023-1034.

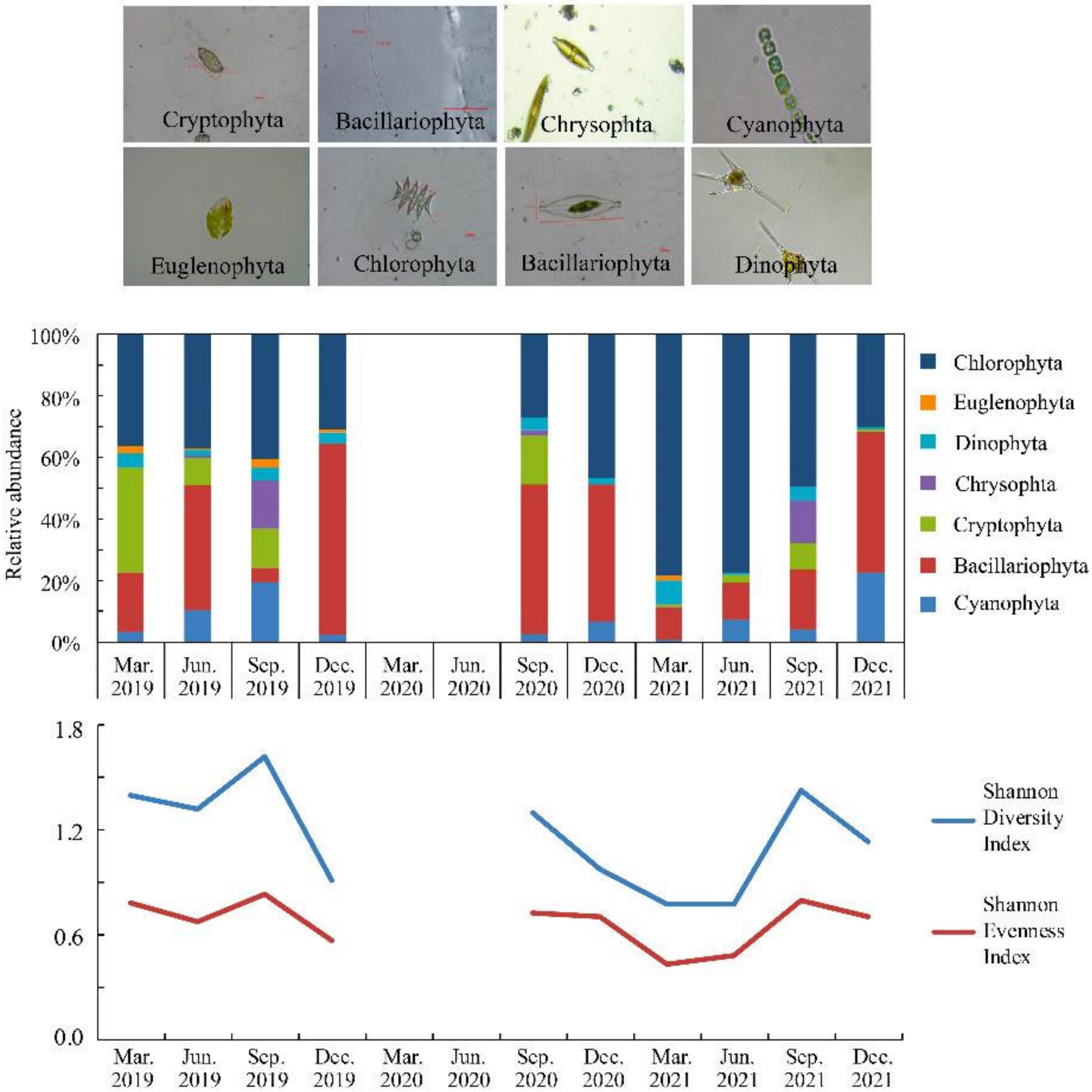



**Figure 15.** The main phytoplankton phyla (top), their relative abundance (centre) and Shannon Indexes (bottom), in the Moon Lake water from 2019 to 2021 with intervals of three months (image © IUE-CAS).

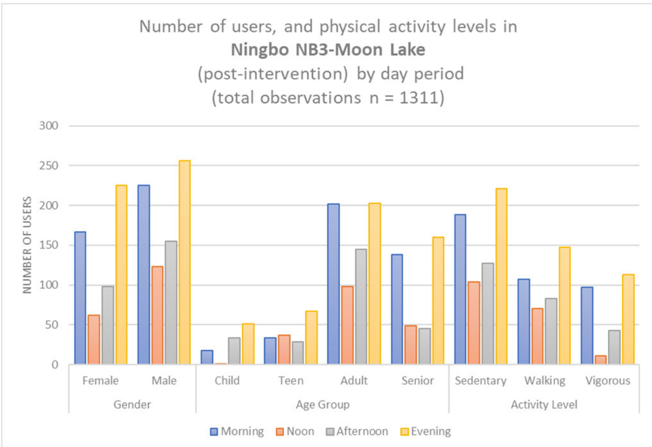
NBS involving many aquatic plants, such as in this case, may also have an impact on air quality mitigation. Indeed, they can stock carbon, as all the plants, and remove pollutants from the atmosphere by respiration and deposition. The impact of the aquatic plants in the Moon Lake on air quality has been assessed by monitoring the PM accumulation on leaves of *A. calamus* and *C. glauca.* by SEM/EDX[16]. These two species are the most planted aquatic plants in Moon Lake. *A. calamus* has the highest total $PM_{10}$ mass accumulated on their leaves, corresponding to 10.0 ± 2.7 μg $cm^{-2}$, while a value of 5.0 ± 0.7 μg $cm^{-2}$ is obtained for *C. glauca*. To obtain the total NBS removal of $PM_{10}$, the total leaf area at the NBS level of these two species should be first evaluated, but this requires the develop of suitable models, not available at this stage.

### *Impact on humans*

Apart from the co-benefits derived to human health from the air quality mitigation, this NBS intervention also provides direct benefits to humans in terms of social (SC 4 and 10), well-being impact (SC 11) and economic impact (SC 12)

The significant implementation cost of the NBS intervention (530000 €) has been completely covered by indirect financial revenues, thanks to the PPP process. In terms of jobs created, 31 persons have been involved in the co-design and implementation, and seven are currently working in NBS maintenance. The number of beneficiaries is highly significant, being >25,000 (both individuals and several companies).

The characteristics of the visitors of the Moon Lake, retrieved from systematic observation assessment (i.e., SOPARC[14]) are presented in Figure 16. Visitors have a mean age of 42±10 years (more adults than seniors or children), are mostly male (58%) and well-educated (i.e., 10 years of education). Nearly all visitors (97%) report visiting the park more than before. Visitors make an average of 14 visits per month, with a mean permanence time of 1 hour. The physical activity performed in the park is 49% sedentary, 31% walking, 20% active, and the main activities are walking, and gaming or doing sports. The perceived restorativeness and social interaction are high (39 ± 5 / 45, and 19 ± 4 / 24, respectively). Visitors rated the various aspects of the quality of the area very positive, with the opportunities for performing physical activity and for meeting people (see Figure 16).



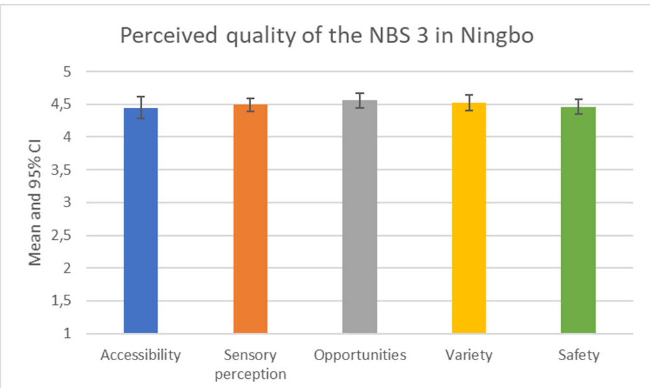




**Figure 16.** Visitor characteristics of the Moon Lake (top) and their perceived quality of NBS3 in Ningbo (scale 1-5, N=78) (bottom).

# 5. Cross-cities comparison: different approaches for different impacts

## 5.1. Community-based urban farms and gardens

Community-based urban farms and gardens are one of the most implemented NBS in all FRCs of proGIreg. Urban farms have the high potential of enabling innovation and experimentation at the neighbourhood level and thus transition to sustainability in cities. They increase accessibility to urban green spaces while serving as a platform for exchanging social values and knowledge in gardening practice. Furthermore, they improve health and well-being through reconnecting with nature[27] (more time spent in open air, making physical activity), being thus mostly connected with SC 8, 10 and 11. While socio-ecological and health benefits take precedence in the practice of urban gardening, the importance of achieving food self-sufficiency and producing healthy food is gaining increasing significance in urban gardens within cities. When food production is also included, these interventions deserve also an economic impact (SC 12). In general, impact on nature is less important in these NBS, since they are mainly realized in already green areas and hosting mainly small plant species and very few trees. However, upon suitable management, they could deserve an interest in terms of biodiversity improvement (SC 5).

In proGIreg, every European FRC implemented a similar NBS, but following different approaches in co-design, implementation and management, which allows to highlight how these aspects are reflected by the assessed impact (Figure 17): NBS3.1: Food forests and permaculture orchard in Huckarde (St. Urbanus) in Dortmund and NBS3.2: Gardens in Cascina Piemonte (Orti Generali) in Turin were fully realized during proGIreg, while NBS3.1: Sesvete City Garden in Zagreb was already existing but it was upgraded with a more sustainable water supply thanks to proGIreg.

**Figure 17.** The community urban farms realized during proGIreg in Dortmund (left) and Turin (middle), and the one already existing in Zagreb (right) that was upgraded thanks to proGIreg (images © proGIreg).

[27] Sonti, N.F.; Svendsen, E.S. (2018) Why Garden? Personal and Abiding Motivations for Community Gardening in New York City. Soc. Nat. Resour, 31, 1189–1205.

Since both Dortmund and Turin community gardens were realized during the project, it is particularly interesting to compare the KPIs assessed for these NBS in terms of impact on social aspects and health and well-being of users. Moreover, this is interesting to be discussed in connection with the different cultural attitude that users from Germany and Italy would have, as well as in connection with the fact that St. Urbanus is a co-managed community garden, where users collaborate in the management of the whole structure, on a voluntary base, while in Orti Generali each user may rent a portion of the garden being the only responsible for that.

As is shown in Figures 18, visitors reported to visit the area more now than before the implementation of the NBS. In Dortmund, 100% of the visitors replied to visit more. In Turin, only 39% of the visitors reported to visit the area more than before implementation, but the average number of visits lays higher, with an average of 9 ± 17 visits per month (compared to 3 ± 3 visits in Dortmund), and an average time spent in the area of 2 hours (compared to 1 hour in Dortmund). In both cities, the main activity performed in the NBS area is gardening, with in Turin more visitors also using the place to socialize with neighbours.

In both cities, relatively more men than women, and relatively more adults than young people, were observed in the NBS (see Figure 18). It might be that male adults and senior people are more attracted to gardening, have more free time and the chance to spent it in the NBS than female or young people. Less than 25% of the visitors was sedentary (12% in Dortmund and 19% in Turin), and a relatively large proportion was vigorously active (65% in Dortmund and 40% in Turin) with gardening as main activity.

Aside from the potential differences in cultural attitudes, the different management approach in both NBS might have led to a different impact in term of frequency and type of use of the transformed spaces. Although both NBS in Dortmund and Turin provide a new space for the community to gardening, the fact that in Dortmund the NBS is managed on voluntary base could have benefited a more inclusive use the new space. In contrast in Turin, where users have to rent a portion of the garden, the access to the NBS might be not affordable for all the community therefore visits have not increased. It is likely the co-management of the garden in Dortmund increases the sense of community belonging, which, in turn, motivates new visits to the NBS.

Also, from the economic point of view, the two NBS are rather different. The co-managed community garden St. Urbanus, Dortmund, is rooted in a low-cost approach. This is reflected by the voluntary involvement as well as the low costs generated in the garden implementation (see Figure 19). The preparation of the area (removing shrubs, laying out of wood chips, designing) and the planting of productive green (fruits, herbs, berry shrubs, mainly) for setting up a food forest relying on permaculture principles required approximately 10000 €. In comparison to Orti Generali, the costs are enormously lower. This must be seen in light of varying objectives. While St. Urbanus community is not aiming for establishing (or increasing) financial revenues, Orti Generali aims for financial self-sufficiency. Thus, the higher implementation costs have to be seen in light of higher job creation (see Figure 19) and significant revenues of more than 150000 €/year.

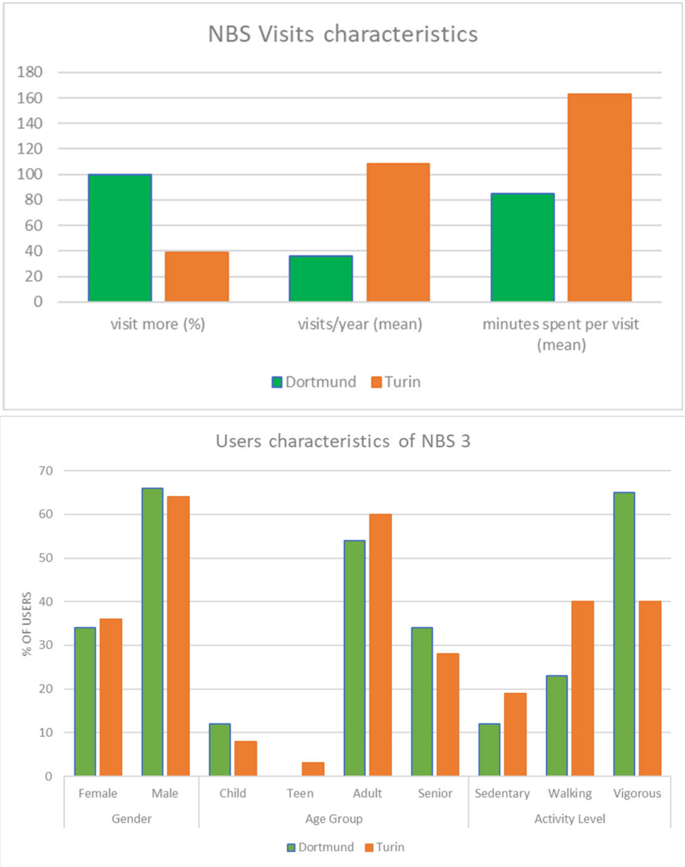



**Figure 18.** Number of visits and time spent (top), and characteristics of the users (bottom) of NBS 3 in Dortmund and Turin (images @ISGlobal)

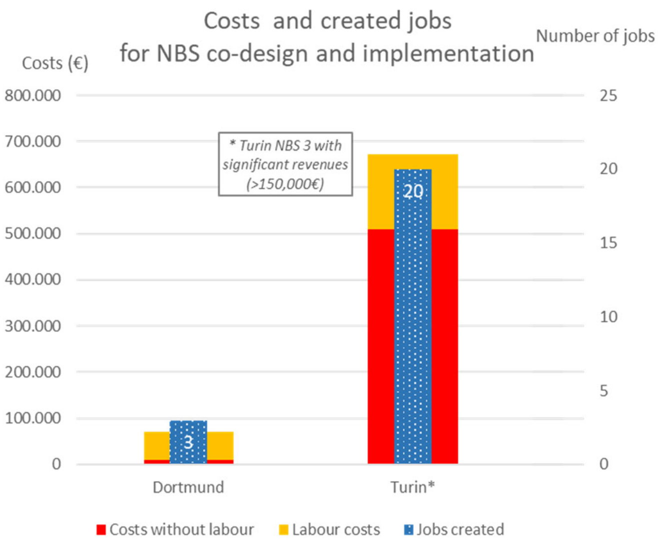



**Figure 19.** Costs and created jobs for co-designing and implementing St. Urbanus food forest in Dortmund and Orti Generali in Turin (images © SWUAS).

Concerning the impact on nature of these NBS, we tentatively explored the dimension of air temperature and air quality mitigation as a consequence of the implementation of community gardens, but no statistically significant differences have been observed across three years between air temperature and $O_3$ and $NO_2$ concentration in the NBS sites with respect to a control site. Only in 2022 a significant decrease in $NO_2$ concentration has been observed in Orti Generali, but this data is too weak to be further discussed. This does not mean that community farms and gardens do not have any impact on air temperature mitigation and quality, but it is rather too low to be measured with the approaches chosen within proGIreg.

The PM uptake by the few trees present in the community farms of the three FRCs has been also evaluated, obtaining that, in general, daily $PM_{10}$ load is higher in Turin Orti Generali (maximum load obtained is 1.1 ± 0.4 ug/cm$^2$ for *M. domestica)* than in Dortmund St. Urbanus (maximum load is 0.4 ± 0.1 ug/cm$^2$ for *C. betulus)* and in Zagreb City Garden (the load for *J. regia* is 0.26 ± 0.06 ug/cm$^2$). However, this does not demonstrate that the atmospheric $PM_{10}$ concentration follows the same trend, since it is well known that PM uptake strongly depends on leaf micromorphology, which is, in its turn, species dependent[28].

The only relevant environmental impact that has been assessed in community garden is in connection with biodiversity enhancement in Orti Generali, where a dedicated activity has been implemented throughout a pollinator monitoring, better described in D4.5[5]. The monitoring surveys, including bees and butterflies, were conducted from 2018 to 2021 along two fixed transects (T1, T2 in Figure 20), according to EU Pollinators Initiative[29] and European Pollinator Monitoring Scheme (EU-PoMS)[30]. An increasing number of species and individuals of both bees and butterflies has been observed from 2018 to 2021, except for butterflies in 2020, possibly due to the lower number of sampling due to COVID-19 pandemic (Table 19). The Shannon Diversity index (Table 10) increases from 0.98 (2019) to 1.85 (2021) for bees while it ranges 1.83-2.33 from 2018 to 2021, being 2018 the year with the lowest value, for butterflies. The Shannon Evenness index (Table 10) shows a weak increase from 0.55 to 0.56 for bees, while it ranges 0.62-1.26 from 2018 to 2021, being 2018 the year with the lowest value, for butterflies.

[28] Sgrigna, G. et al. (2020), Relationships between air particulate matter capture efficiency and leaf traits in twelve tree species from an Italian urban-industrial environment, Science of the Total Environment 718, 137310.
[29] Underwood, Darwin, Gerritsen, (2017), Pollinator initiatives in EU Member States: Success factors and gaps. Report for European Commission under contract for provision of technical support related to Target of the EU Biodiversity Strategy to 2020 – maintaining and restoring ecosystems and their services. ENV.B.2/SER/2016/0018. Institute for European Environmental Policy, Brussels.
[30] Potts et al. (2020), Proposal for an EU Pollinator Monitoring Scheme, EUR 30416 EN, Publications Office of the European Union, Luxembourg.

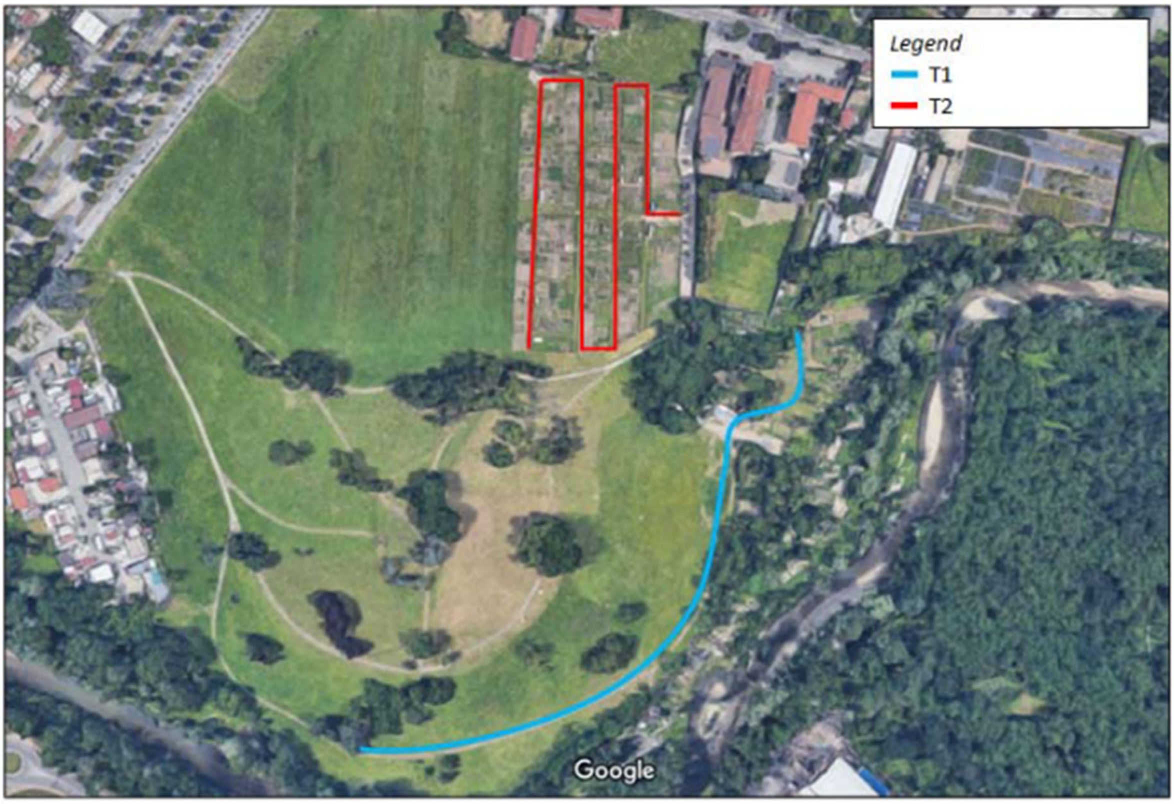



**Figure 20.** Transect walk of pollinator monitoring carried out in Orti Generali (images © UNITO).

**Table 19.** Number of species and individuals of bees and butterflies detected along the transects in Orti Generali (2018-2021 period).

| Year | Bees Number of species | Bees Number of individuals | Butterflies Number of species | Butterflies Number of individuals |
|---|---|---|---|---|
| **2018** | 3 | 41 | 19 | 291 |
| **2019** | 6 | 289 | 29 | 782 |
| **2020** | 21 | 427 | 22 | 194 |
| **2021** | 27 | 796 | 31 | 957 |

## 5.2. Green walls and roofs

The use of GI on buildings as a natural solution to provide a range of ESs to the urban environment is becoming ever more important in Europe and worldwide. In this context, the role of plant systems applied to outdoor buildings' surfaces, such as green walls and roofs, is central to containing the environmental impact caused by human activities, as well as to the renaturation and decarbonisation of cities and the mitigation of extreme weather phenomena caused by climate change[31]. These solutions have numerous benefits due to the physiological properties of plants, which, through transpiration, consume energy in the form of latent heat to effect phase changes from water-to-water vapour and in this way reduce the ambient temperature (SC 1). Through photosynthesis, they also consume carbon dioxide ($CO_2$) in the atmosphere, thereby promoting decarbonisation (SC 1), and contribute to air quality mitigation by removing GHG through stomata and PM by deposition (SC 6). Finally, if properly managed, they can also provide habitats for living organisms, thus impacting biodiversity (SC 5).

Such NBS deserve thus a major attention in connection with environment benefits, but a number of co-benefits for humans can also be mentioned. Indeed, air quality is a parameter closely linked to human health (SC 11), as well as air temperature mitigation is connected with the improvement of human health and the reduction of energy consumption for cooling the buildings (SC 12). Moreover, the exposure to green surfaces may deserve an interest in term of human well-being and improved mental health (SC 11).

Three NBS in this category have been implemented in proGIreg (Figure 21):

- NBS5.4 – New green roof at WOW in Turin - an extensive green roof of 140 sqm. on a public but currently abandoned building, intended to be a "natural lawn" obtained by sowing a mixture of seeds from stable meadows of northern Italy;
- NBS5.3 – Green wall outdoor on a homeless dormitory in Turin - a green wall of 80 sqm, 3 meters high, realized as a self-supporting structure set-off from the wall of the building;
- NBS 4/5: Green Roof/Photovoltaic cells/Green wall & Aquaponics testing installation in Zagreb – a mini urban farm designed as a new complete solution that integrates a green wall and an extensive green roof composed by a mix of plant species, with aquaponics technologies and has both commercial and educational functions.

The impact of such NBS implementations on air temperature mitigation has been evaluated by comparing the internal and external temperature of the buildings with a reference temperature monitoring station nearby.

[31]Dover, J. W. (2015) Green infrastructure: incorporating plants and enhancing biodiversity in buildings and urban environments. Routledge Ed.

**Figure 21**. Top left: overview of the Green Roof realized on the WOW building in Turin (image © City of Turin); top right: the Green Wall realized on the homeless dormitory in Turin (image © City of Turin); bottom: the seedling factory with the green wall (left) and the green roof (right) (image © M. Ristorini and A. Campiotti).

The air temperature on top of the new green roof at WOW was monitored on top of the roof and on a control point, from 14 February 2020 to 29 March 2023. The monthly mean of the daily maximum temperatures of the NBS and of the control point are compared in Figure 22. It is evident that, at the beginning of 2020, when the vegetation cover had not yet developed, the air temperature was highest near the NBS, with differences of up to 10°C. As the months go by, and the vegetation develops, the temperature difference decreases until the air temperature near the NBS and the temperature near the control point become homogeneous. This trend is confirmed in subsequent years 2021 and 2022, where there is no significant difference between the two temperatures.

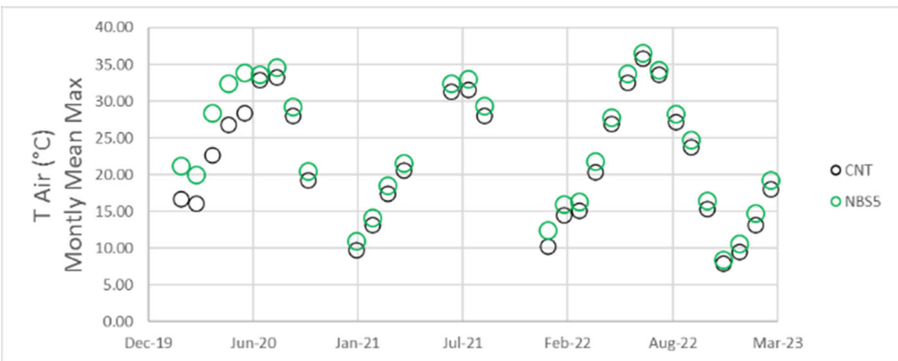



**Figure 22**. Maximum daily temperature on the New green roof at WOW measured from 14 February 2020 to 29 March 2023, compared with the temperature measured at a reference site (image @ CNR)

The air temperature inside and outside the homeless dormitory in Turin were monitored by Regional Agency for the Protection of the Environment (ARPA) of Piemonte before and after the wall installation (occurred in November 2020). Outside the structure, sensors were placed in the gap between the building wall and the green wall. As a reference, the temperature of an ARPA monitoring station located in the Mirafiori district was used. To make evident the effect of the wall, the daily maximum temperature measured outside and inside the shelter are compared with the daily maximum temperature measured by the reference station in August 2020 and in August 2021 in Figure 23. In August 2020, the mean of maximum daily temperatures measured by the reference station is 31.2 ± 1.9 °C, while outside the shelter is 41.0 ± 4.5°C and inside the shelter is 33.3 ± 2.0°C. In August 2021, the mean of maximum daily temperatures measured by the reference station is 30.5 ± 2.5 °C, while the average outdoor temperature at the shelter is 36.2 ± 4.0°C and the average indoor temperature is 32.0 ± 2.2°C. The presence of the green wall is thus able to decrease the outdoor-indoor difference of the shelter from 7.7 ± 4.9 °C (2020) to 4.2 ± 4.6 °C (2021). This difference is due partially to the presence of green wall, but it depends also to the lower temperature reached in summer 2021 than in 2020. However, the differences between shelter indoor and reference station temperatures are lower than the outdoor-indoor differences. These differences reached a peak of 5°C in 2020, and only 2.5°C in 2021.

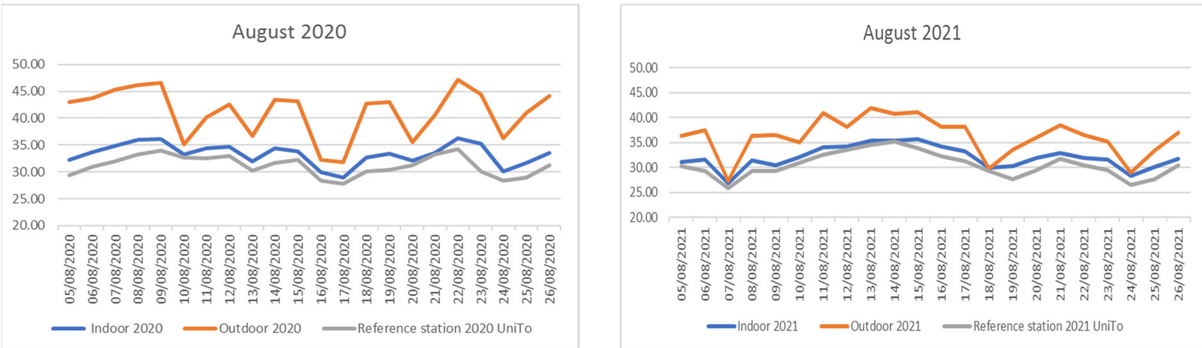



**Figure 23.** Maximum daily temperature inside and outside the shelter as measured in August 2020 and August 2021, compared with the temperature measured by a reference station (image @ CNR).

Finally, the air temperature inside the mini urban farm in Zagreb was monitored from 14 July 2022 to 21July 2023 (Figure 24). In this case, pre-installation data are missing (installation occurred in August 2021) and the temperature outside of the mini farm, close to the roof, has been measured only from 14 July 2022 to 28 August 2022. As a reference, a monitoring station located in Sesvete was used. In July 2022, the average daily maximum temperature was 43.3 ± 6.5°C outside the mini farm, at the green roof level, and 27.8 ± 2.0°C inside the farm, while it was 36.0 ± 4.1°C at the reference monitoring station. In July 2023, the average daily maximum temperature was 28.2 ±.1.8 and 35.8 ± 3.8°C at the reference station. Again, a high difference is observed among the outdoor and the indoor temperatures in summer period for the mini-farm (about 15 °C), while the difference between the indoor temperature and the reference station is lower and almost constant (about 7 °C).


**Figure 24.** Maximum daily temperature inside the mini-farm in Sesvete – Zagreb, compared with that measured by the district reference station in July 2022 and July 2023 (image @ CNR)

In conclusion, the just discussed results show that a green wall or roof (or a combination of them) can mitigate the inside temperature of a building, as well as the surrounding temperature, by reducing the heat flow in and out the building thanks to plant biomass, thus improving the energy efficiency of the building itself.

The second evaluated impact is on air quality mitigation. Being the new green roof at WOW mainly a meadow, changes in air quality were evaluated measuring the ppb concentration of atmospheric ozone ($O_3$) and nitrogen dioxide ($NO_2$) close to the roof and in a control site, by passive samplers, in 2019, 2021 and 2022 (Figure 25). It has been observed that ozone concentration near the NBS decreased from 60.9 ± 1.2+ ppb in 2021 to 54.3 ± 7.9 ppb in 2022, while the concentration at the control point increased from 58 ± 4 ppb to 78 ± 9 ppb. A similar effect is seen for the $NO_2$ concentration, which decreased from 9.0 ± 0.2 ppb to 8.5 ± 0.1 ppb close to the roof, while it increased from 11.5 ± 0.5 ppb to 12.9 ± 0.2 ppb at the control point.

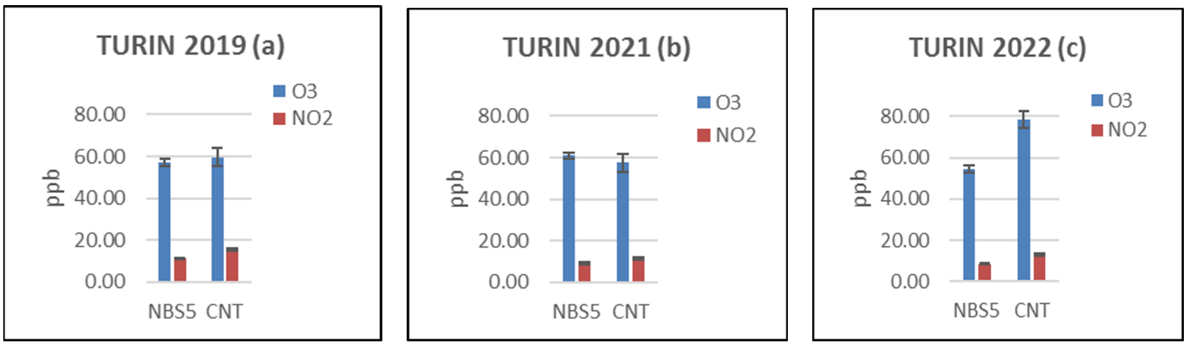



**Figure 25.** Concentrations (ppb) of $O_3$ (blue columns) and $NO_2$ (red columns) in NBS5.4 and in a control point, in 2019, 2021, 2022.

The impact on air quality of the two green walls was instead assessed by measuring the capability of the walls in $PM_{10}$ removal from the atmosphere. To do this, leaves of all the species used in the two walls were sampled and the density (number of particles per unit leaf area in $mm^2$), size distribution, chemical composition (relative weight W% per chemical element) of the PM particles adsorbed on the leaves were evaluated by SEM/EDX[16], to obtain the PM load (µg per unit leaf area in $cm^2$) removed by each species. Upon proper upscaling, this information will allow to obtain the whole wall PM removal potential.

Furthermore, it represents an important knowledge in terms of species-specific efficiency, to be further used in the design of future similar NBS implementations.

In the Turin Green wall, leaves from *Bergenia cordifolia* Moench, *Carex flacca* Schreb., *Geranium cantabrigiense* P.F. Yeo, *Rosmarinus officinalis* L., *Teucrium chamaedrys* L. were sampled and the results about removed PM load are shown in Figure 26 (left). *Bergenia cordifolia* is the most effective plant species of this NBS, by capturing about 10 µg/cm$^2$ of $PM_{10}$, while the other plant species removed about 2 and 4 µg/cm$^2$.

From the green wall at the urban mini farm in Zagreb, leaves from *Allium schoenoprasum* L., *Ocimum basilicum* L., *Origanum* spp., *Salvia officinalis* L., *Thymus vulgaris* L. From were sampled. The PM load obtained are shown in Figure 26 (right), revealing that *Thymus vulgaris* is the most effective plant species of this NBS in PM capture, by capturing about 18 µg/cm$^2$. However, thanks to the high size fraction resolution allowed by the SEM/EDX technique, it can be highlighted that *Ocimum basilicum* and *Origanum* are much more efficient in $PM_{2.5}$ removal, (having a load of 6 µg/cm$^2$ and 4 µg/cm$^2$, respectively), and this is particularly important since $PM_{2.5}$ is much more harmful than $PM_{10}$. This further shows that the removal of atmospheric PM in its different dimensions is species-specific and depends on the morphological and physiological characteristics of the plant.

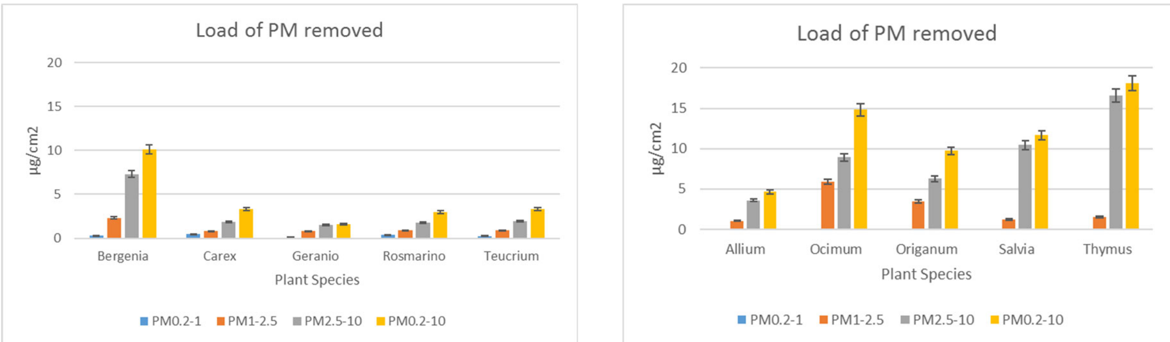



**Figure 26**. Load of PM removed (µg/cm$^2$) and standard errors, as obtained from SEM/EDX, through the combination of PM density and chemical composition results, from the plant species present in the Turin (left) and Zagreb (right) green walls.

Even if focused on environmental benefits, as previously said, the presence of green wall and roof may have an impact also on humans. Co-benefits can derive from reducing the internal temperature (both economics and for health) end mitigating air quality (for health), but also a direct impact on social aspects and well-being can be observed. This last aspect was tested in Zagreb, but unfortunately, since the mini farm is still not open to public, the number of interviewed people was very low (4). For this reason, only raw scores have been collected. The mean obtained score are: perceived social support (scale 0-24) = 17; perceived social cohesion (scale 0-5) = 2; perceived restorativeness of the NBS (scale 0-45) = 30.75. Data suggests a positive impact in terms of perceived social support and restorativeness. However, no statistical analysis could be performed due to the low number of participants, thus, a judgement on the effectiveness of the monitoring is not feasible.

## 5.3. Accessible green corridors

Green corridors are an excellent way to provide accessible green space with the additional advantage of motivating users to be physically active. Green corridors are mainly used to cross from one area to another, and if they are implemented well, citizens are willing to make a detour to enjoy the green and quiet path as compared to a shorter route with more motorized traffic[32]. Thus, these solutions mainly provide benefits to humans, improving social interactions (SC 10) and health and well-being (SC 11) thanks to the change in land use occurred (SC 8). However, a proper management, may also deserve interest in connection with environmental benefits, such as biodiversity enhancement (SC 5).

Within the proGIreg project, in the three European FRCs, a green corridor was implemented (or will be, in the case of Zagreb where the implementation is planned to be completed in the beginning of 2024). In Dortmund, as explained in more detail in section 4.1, a 115 m long cycling/walking route was created which connects the Huckarde Borough with the renatured River Emscher and with the recreational areas on the former landfill site in Deusenberg (see image in Figure 27). In Turin, local natural heritage was renewed, and a green corridor was created transforming a road stretch connecting the residential area of the Mirafiori district with the Mirafiori Castle and Piemonte Park. Grass, shrubs and trees were planted, and landmarks/signs were placed providing information of the site (see Figure 27). In Zagreb, the green corridor will be a cycling and walking path that crosses a post-industrial site.

**Figure 27**. Green corridors in Dortmund (left; image @ Axel Timpe) and Turin (right; image @ UNITO).

In both FRC where this NBS was implemented before the end of the project (i.e., Dortmund and Turin), observations were performed before and after implementation of the NBS to count the number of visitors and assess their gender, age group, physical activity and type of activity (see Figure 28). In Dortmund, the number of users increased significantly with approximately 15.0 ± 7.6 visitors more per day than before implementation ($p$=.002). In Turin, there was a higher number of visitors before the implementation of the NBS, and fewer visitors were observed after implementation of the NBS. This decrease in observed visitors might be explained by the COVID-19 pandemic. The pre-implementation observations took

[32] Žlender, V., & Thompson, C. W. (2017). Accessibility and use of peri-urban green space for inner-city dwellers: A comparative study. Landscape and urban planning, 165, 193-205.

place in September 2020, in a period after strict lock-down but with still many pandemic-related measures impeding citizens to live their life as usual. It was observed that in these periods, people were walking more. The post-implementation observations in 2022 probably refer to a more 'normal' situation in which people go to work and school as usual. This is also reflected in the lower number of teens and adults that were observed in 2022 compared to 2020. In Dortmund, visitors of the NBS area are mainly adults (no children were observed), with a relatively equal gender distribution. In Turin, more men than women visit the area (but take into account that the Turin population has a higher proportion of male inhabitants).

An important way via which time spent in green spaces benefits overall health, is by means of an increase in physical activity. In both cities, the green corridor areas were mainly used for walking, which already entails health benefits. In addition, in both cities, there was an increase in moderate- to vigorous-intensity physical activity after implementation of the NBS. In Dortmund, besides walking (or walking the dog), some citizens used the green corridor for jogging and cycling, and rarely to sit down, even if a new bench was placed as part of the intervention. In Turin, walking was also the main activity in the green corridor area. Also here, citizens were observed jogging and cycling, and children playing, but a higher proportion of people were observed seated. Overall, there is a clear increase in the physical activity of users of these green corridor areas, creating a positive impact on health and health-related costs (see the health impact assessment reported in D4.8[11]).

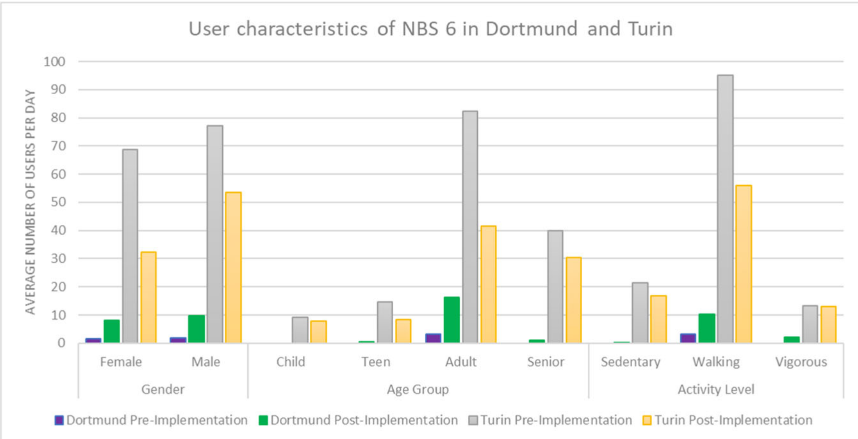



**Figure 28.** Number and characteristics of users at pre and post-implementation of the NBS6 in Dortmund and Turin. Pre-implementation SOPARC assessment took place on 15, 17, 19 and 20 September 2020 in Dortmund, and on 29 September, 1,3 and 4 October 2020 in Turin. Post-implementation SOPARC assessment took place on 21, 22, 24 and 25 March 2022 in Dortmund and on 26, 27 September and 2, 8 October 2022 in Turin.

However, when suitably designed, also green corridors may deserve an interest in terms of ecological and environmental benefits, as demonstrated by the Turin case. The Turin NBS6 was indeed co-designed and created near NBS3 Orti Generali, ideally to also allow pollinators and not only humans to move along the route. To make the corridor work, it has been necessary to find plant species (tree, shrub and herbaceous) foraging by bees and butterflies considering these following points:

1. The plants have to satisfy the need for different heights, in order to have a positive effect on biodiversity, as there are many different spaces and heights that attract small mammals, arthropods and the insects themselves.

2. The plants used must be native. In fact, a positive relationship between pollinators and the proportions of gardens in which they are planted has been demonstrated for them and the need for the use of native plants in urban gardens and green areas is emphasised to ensure that specialist pollinators can find the necessary nourishment, which, unlike generalists, are poorly adapted to visiting alien species.

3. The plants employed must be nectariferous, polliniferous and host for butterfly caterpillars. They guarantee a food source and food sources for the larvae. These two prerequisites are essential in order to encourage pollinators to move from one area to another, which is advantageous to them.

4. The plants used must form colourful patches as they must be visible in terms of size and colour (yellow, pink, white, blue and violet blooms).

5. Finally, the blooms must be scalar and ensure supply throughout the pollinator flight period.

In addition to these requirements, there is also the need to use plants that are relatively robust and able to survive in non-ideal conditions of soil, radiation and climate, including: *Corylus avellana*, *Tilia* spp., *Prunus avium*, *Frangula alnus*, *Hedera helix*, *Alliaria petiolata*, *Rumex* spp., and various aromatic species. Numerous sources were compared, and a table divided into flora useful for different pollinators was drawn up. An initial skimming was then carried out to reduce the number of plants of possible use and to simplify the process of finding plants, from over 190 to 34. To address the needs of co-design, the 'construction' of the corridor was a participatory process, involving the citizens, especially residents.

Along the green corridor, a monitoring of butterfly community was carried out to evaluate the success of the implemented NBS. For this purpose, the Pollard transect method was used[29], which consists of walking a fixed route along which the butterfly species and individuals for each species are counted. The transect was conducted in the years 2020-2021 from April to September to cover the main flying period. Observations were carried out between 10.00 a.m. and 3.00 p.m., avoiding particularly windy or rainy days. The monitoring has been carried on also during 2022 and 2023, after the expected period required by the proGIreg project thanks to the researchers of the University of Turin, involved in the EU Butterfly Monitoring Scheme project[30]. The collected data show that both the number of species and individuals of butterflies increase from 2020 to 2023 (Table 20). In the year 2022, there was a drastic decline in the number of species and individuals, probably due to the intense heat in summer and green area management. The Shannon Diversity and Evenness indexes, calculated as KPI's for the years 2021, 2022 and 2023 (Table 14), ranges between 1.73-2.03 and 0.59-0.89, respectively.

**Table 20.** Number of species and individuals or butterflies detected along the Green Corridor (2020-2023 period**).**

| Year | Butterflies<br>Number of species | Butterflies<br>Number of individuals |
|---|---|---|
| **2020** | 3 | 12 |
| **2021** | 16 | 154 |
| **2022** | 7 | 14 |
| **2023** | 18 | 121 |

## 5.4. NBS for vulnerable populations

One of the main challenges in proGIreg was the involvement of vulnerable population in co-creation and co-maintenance processes, as well as users of the implemented NBS. The assessment of the impact that the implemented NBS have had on these people thus deserve a major interest. Among our cases, five specific target populations have been identified as 'vulnerable.' Specifically:

- the users of NBS 3.2: Sesvete City Garden –Therapeutic Garden in Zagreb, which are individuals with multiple disabilities, including motor, linguistic, and intellectual disabilities (e.g., intellectual disability and/or psychiatric conditions);
- the participants to the intervention called 'Farfalle in Tour' in Turin, within the action of NBS 8: Butterfly gardens for disadvantaged people, which are both individuals with multiple disabilities, such as for the Zagreb Therapeutic Garden, and children from primary schools (two target populations);
- the children in the school where the NBS 5.2: Green wall indoor at school was realized;
- The homeless using the shelter where the NBS 5.3: Green wall outdoor at a homeless shelter was realized.

The children's users of the "Farfalle in Tour" and the users of the shelter were then evaluated as not enough stable and homogeneous samples to be tested. Thus, the other three groups of NBS users were selected for impact assessment (NBS' pictures are in Figure 29). These NBS were realized with a focus on improving social aspects and mental health (SC 10 and 11). However, "collateral" effect on environment may occur, such as the improvement of indoor air quality (SC 6).

**Figure 29.** Therapeutic Garden in Zagreb (left, @City of Zagreb), “Farfalle in Tour” in action in turin (Center; @UNITO) and Green Wall in the school in Turin (image © City of Turin).

Collecting data from vulnerable populations through questionnaires or scales can be challenging for several reasons. Vulnerable populations, such as individuals with mental health issues, low literacy levels, or those experiencing socio-economic disadvantages, often face barriers to effective communication and participation. Language and literacy barriers may hinder their ability to understand and respond to complex survey questions. Additionally, the stigma associated with their vulnerabilities may lead to social desirability bias, making respondents hesitant to disclose sensitive information. Ensuring the privacy and confidentiality of their responses can also be a concern. Mistrust of researchers may further complicate data collection efforts. To overcome these challenges, researchers must employ culturally sensitive and tailored data collection methods, prioritize participant comfort and privacy, and employ trusted intermediaries or interviewers to establish rapport and enhance data quality.

Thus, after the implementation of NBS, instead of using the standard NBS visitor questionnaire, we employed either a simplified approach called “keyword cloud”[33] to gather feedback on the experience with the newly implemented NBS, for people with disabilities, or a suitably developed version of the questionnaire, for children[5].

A keyword cloud, also known as a word cloud or tag cloud, is a visual representation of text data, where words or phrases are displayed in varying sizes or colours, with the size or colour indicating the frequency or importance of each term within the given text. In a keyword cloud, the most frequently used words or phrases in a document or dataset appear larger or more prominently, making it easier to identify the most common or significant terms at a glance. Keyword clouds are often used to provide a quick overview of the main topics or themes within a text and are frequently employed in data visualization, information retrieval, and text analysis applications.

Data for keyword cloud generation from the users of the two selected NBS were collected by volunteers or specialized people that work with the target sample participants. They should provide to users the instructions: “Please, indicate a list of ten words related to (NBS and/or the experience related to it). You can use any words to define it, including nouns, adjectives, and verbs. The words can have both positive (e.g., enjoyment) and negative (e.g., boredom) connotations. All information will be collected and processed anonymously”. In the event that

[33] Helic, D. et al. (2011), Are tag clouds useful for navigation? a network-theoretic analysis. International Journal of Social Computing and Cyber-Physical Systems, 1, 33-55.

participants were unable to express their own opinions, proxy respondents were utilized, including operators, parents, or educators capable of detecting the emotional expressions of the participants themselves. Once the list of adjectives was collected, they were entered into an online word cloud generator. Figures 30 show the graphical representations of the two keyword collections.

It is evident that most words used to describe the NBS-related experience were perceived as positive. In addition to positive emotions, it is worth focusing on words related to behavioural actions such as studying, working, and resting. Therefore, we can speculate that these experiences not only elevated the levels of positive emotions but also activated the participants, especially in the case of the population benefiting the therapeutic garden, who are at high risk of hypo-stimulation. We can conclude that the implementations of NBS 3.2 in Zagreb and NBS 8 in Turin were successful.


**Figure 30.** Keyword clouds related to data collection in NBS3.2: Sesvete City Garden –Therapeutic Garden in Zagreb (left) and NBS8: Butterfly gardens for disadvantaged people in Turin (right).

Concerning the impact on children in Turin, it is now consolidated in the literature that participation in activities in environments that allow contact with natural elements promotes healthy development and, in general, a feeling of well-being on a psycho-physical level for children[34]. The purpose of the NBS-visitor questionnaire for children is to monitor any changes in the child's well-being in terms of pro-environmental behaviours of children and their perceived well-being in relation to the performance of activities inside the school where elements that recall natural environments are present. Children are asked to answer some questions under the supervision and support of teachers. Baseline and follow-up data were acquired. Indicators assessed at the baseline are pro-environmental behaviour and attitude. Furthermore, perceived restorativeness of NBS was acquired through an adaptation of the version for adults used in the NBS-visitor questionnaire (see D4.5[5] for more details).

Post-implementation data should have been acquired after one year from the baseline; however, due to Covid-19-related restrictive measures, the follow-up has been postponed in the subsequent academic year; this implying that some participants to the baseline

[34] Mygind, L. et al. (2019), Mental, physical and social health benefits of immersive nature-experience for children and adolescents: A systematic review and quality assessment of the evidence. Health & place, 58, 102136.

assessment were no more available in the school. In total, 70 children were interviewed, from 4 class groups (analysis were run per class group): 15 children attending the 4$^{th}$ grade class (4A; 9-10 years-old), 23 children attending the 4$^{th}$ grade class (4B; 9-10 years-old), 14 children attending the 5$^{th}$ grade class (5A; 10-11 years-old), and 18 children attending the 5$^{th}$ grade class (5B; 10-11 years-old).

Detailed statistical analysis of the data is reported in the Annex 1. In general, the intervention of implementing an indoor green wall in a school of Turin was found to be not sufficient for leading to a positive change in the two considered outcomes on children. Pro-Environmental Attitude showed no significant changes between pre and post implementation in any class. Pro-Environmental Behaviour was increased in schoolchildren of one class only (5A) after the implementation of the green wall. We can speculate that schoolchildren have only been exposed to the wall for a short time, due to COVID-19 restrictions, and this did not allow them to benefit from it from a social perspective, at a measurable scale.

The same was observed for the impact of the indoor green wall on air quality. Indeed, the impact of green wall on indoor air quality mitigation has been largely proved[35], also in connection with carbon mitigation, due to $CO_2$ removal[36]. However, critical experimental conditions must be set, in order to obtain reliable results and, thus, measure the corresponding impact. In the case of the indoor green wall realized in Turin, ARPA Piemonte measured the concentrations of atmospheric and gaseous pollutants such as, Volatile Organic Compound, formaldehyde and higher aldehydes and nitrogen dioxide $NO_2$ at the end of 2020 (pre-implementation) and beginning 2021 (post-implementation). However, the measurements did not show any significant impact of the green wall, likely due to the increased ventilation, due to the COVID-19 contrast measures for indoor and public spaces.

Nevertheless, we have demonstrated that the green wall effectively removes $PM_{10}$ from the school air by studying the PM adsorbed on the surface of the green wall leaves, sampled from the five cultivated vegetable species used: *Chalathea orbifolia* H. Kenn, *Chamaedorea elegans* Mart, *Chlorophytum comosum* Thumb, *Marantha leuconeura* E. Morren, *Pilea peperomioides* Diels. By SEM/EDX microanalysis of leaves[16], deposited particles density (number of particles per unit leaf area in mm$^2$), chemical composition (W% of each chemical element for each plant species) and weight of PM removed (µg per unit leaf area in cm$^2$) are obtained. In Figure 31, the PM10 per unit leaf area (PM load) of the five species as measured from leaves sampled in October 2021 and October 2022. The amount of deposited PM significantly increases from one year to the other, due to the continuous PM accumulation on leaf surfaces. Indeed, in indoor green wall, no mechanical removal action naturally occurs, such as due to rain in outdoor wall. In particular, the $PM_{10}$ load increases from 5.7 ± 0.3 to 9.0 ± 2.2 ug/cm$^2$ for *Calathea orbifolia* (+58%), from 6.0 ± 1.1 to 10.9 ± 1.7 ug/cm$^2$ for *Chamaedorea elegans* (+82%), from 5.1 ± 1.0 to 13.0 ± 0.5 ug/cm$^2$ for *Chlorophytum comosum* (+155%), and from 3.6 ± 0.7 to 10.7 ± 3.5 ug/cm$^2$ for *Pilea peperomioides* (+197%), while for *Marantha leuconeura*

[35] Pettit, T. et al. (2019), The in-situ pilot-scale phytoremediation of airborne VOCs and particulate matter with an active green wall, Air Quality, Atmosphere & Health, 12, 33–44.
[36] Shao, Y. et al. (2021), The Impact of Indoor Living Wall System on Air Quality: A Comparative Monitoring Test in Building Corridors, Sustainability 13, 7884.

any significant change is observed. This provides information not only for the evaluation of this green wall potential, but also for the future implementation of efficient indoor green wall.

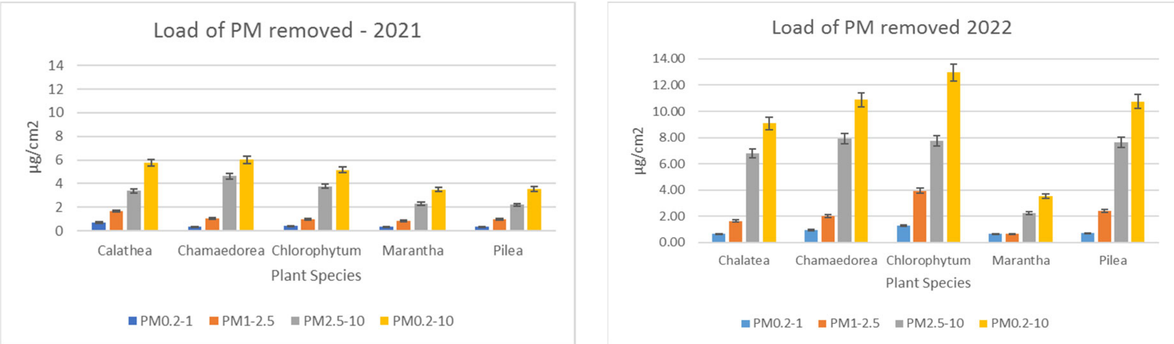



**Figure 31.** Load of PM removed (µg/cm$^2$) and standard errors, as obtained from SEM/EDX, through the combination of PM density and chemical composition results, from the five species present in the wall in October 2021 (left) and in October 2022 (right).

# 6. Conclusions

ProGIreg was a 5-years and a half project dedicated to the implementation of eight different types of NBS in post-industrial districts, within a Living Lab (LL) approach, and with productivity of the implemented NBS being key. The benefits provided by these NBS interventions to humans and nature have been assessed by evaluating their impact on socio-cultural inclusiveness, human health and well-being, economy and labour market, and ecological and environmental restoration, to provide a holistic description.

In particular, the impact of the four LLs has been assessed at the district scale, and it has been presented in D4.8[11], while the impact of 17 NBS implementations has been assessed at the local (i.e., NBS) level, and presented in this deliverable. Such local impact has been assessed by evaluating 33 different Key Performance Indicators (KPIs), related to 9 of the 12 societal challenge areas identified as relevant for NBS by the European impact assessment framework[4]. The number of evaluated KPIs per implementation was depending on the expected impact, availability of pre-implementation baseline data or capability of collecting them according to the implementation timing, and expertise of the local partners involved in data collection. Among the 33 KPIs selected for impact assessment, 30 belong (or are related to) the European assessment framework for NBS[4], while 3 were newly introduced. Among the KPIs from the European framework, 10 are “Recommended” ones, while the other 20 are “Additional”.

Three success stories have been identified in proGIreg, in connection with the aim of the project and with the most recent and agreed definition of NBS[12]. They have been implemented in the FRCs of Dortmund (the restoration of a former landfill), Turin (the production of new soil from urban waste and its use to create new green areas in the same city) and Ningbo (the regeneration of an urban lake funded by a public-private-partnership) and have had a positive, significant impact in connection with several societal challenges, concerning both humans and nature. Apart from their significant impact, and likely behind it, the common characteristics that made these case studies successful are:

- **Innovation.** Innovative partnerships among stakeholders from different fields have been put into action to introduce beyond new business models (by integrating sustainable solar energy or soil production with ecosystem regeneration actions, such as in Dortmund and Turin, respectively) or governance (based on public-private partnership, such as in Ningbo).

- **Quadruple helix approach.** This aspect, which is partially connected with the previous one, guaranteed the involvement of different types of stakeholders, having different goals to reach, and thus providing a holistic impact. For instance, the involvement of SMEs allowed to obtain significant financial revenues and number of new jobs created, which are essential prerequisites (or at least are expected to favour) for long-standing maintenance of the implementation itself, which is currently an open issue in NBS implementation. On the other side, the involvement of researchers in the co-design allowed a reliable and robust monitoring to be carried on, facilitating the impact evaluation. At the same time, the involvement of local authorities and civil society sectors made easier the identification, and the addressing, of local population needs in terms of social and well-being aspects.

- **Design at scale.** This is particularly relevant if ecosystem-based approaches are to be put into action. Moreover, changes produced (or expected/foreseen) on the surrounding environment can be measured only if the NBS intervention is designed at scale, especially if included into an already green context. The same is true for their impact on humans: having a significant number of people getting into contact with the NBS implementation allows both the application of reliable statistical approaches (which require a minimum number of participants in the sample) and a significant economic and labour market impact. Thus, only NBS designed at scale (or sufficiently networked at a larger scale) allows the required monitoring/evaluation/adaptation loop that is included into the NBS definition.

- **Suitable for upscaling / replication.** Upscaling and replication are key, if NBS are conceived as building blocks for future transformative changes, and the three success stories identified represent great examples of NBS to be upscaled / replicated in the future in the same context or in other contexts, upon being adapted to the local situations.

These aspects make the proGIreg success stories particularly interesting as example of NBS to be implemented in the future, to pave the way towards societal just transformative changes.

The other proGIreg NBS implementations for which a significant impact has been evaluated, belong to more “traditional” NBS types, such as urban garden, green walls and roofs, and green corridors. They are interventions mostly focusing on single impact domains, such as social cohesion for the urban gardening, climate change mitigation for green roofs and walls, and human well-being for green corridors. However, we have demonstrated that, when properly planned and monitored, these NBS can have a significant impact also in connection with other societal challenges.

For instance, thanks to the synergy among stakeholders and the involvement of local researchers’ expertise in biodiversity conservation and monitoring, the “Orti Generali” urban farming and the closely connected green corridor in Turin, not only have improved the social cohesion perception and the physical activity of users, but also the pollinator biodiversity, despite being realized in already green areas (which avoided, on the other side, any other significant environmental impact).

In the case of the green roofs and walls, a clear mitigation effect is obtained upon the NBS' implementation on both the indoor and the outdoor temperature of the buildings (this latter being measured in the proximity of the NBS). However, by suitably studying the leaves of the plants used to build the green walls, an estimation of the impact of air quality mitigation has been obtained, according to the plant species used, which also deserve interest for the selection of the plant species in future NBS implementations.

Indeed, the main problem encountered for impact monitoring of proGIreg interventions has been its suitability to be measured. Many implementations were too small, or were included in an already, much larger, green space, or impacted too few people, or vulnerable people. All these factors prevented robust, scientific approaches to be applied. In other cases, the implementation was concluded in delay, and there was not enough time to let the effect become evident within the project lifespan. Or the required competences were not available on the ground and thus the monitoring activities were not run at all, or they were run but not consistently enough, thus providing data that could not be used to assess the impact.

In some cases, these difficulties have been mitigated by adapting the monitoring tool. For instance, some data required for temperature monitoring were missing, but they have been retrieved from institutional databases. Or, in case of vulnerable population involved as users, new adapted methods have been developed during the project, which allowed to obtain at least a qualitative description of the NBS impact on such users.

A few lines should be finally spent commenting the possible impact of COVID-19 pandemic and earthquake in Zagreb on impact monitoring. For sure, they have had an impact on NBS implementation timing, but this gap has been almost filled by the project extension. They could have had an impact in monitoring, due to lockdown restrictions that limited the mobility of people involved in data collection, but luckily the restrictions were mostly in 2020, when very few monitoring actions where planned, since the NBS were still under implementation or just concluded. Less clear is the impact that these two episodes may have had on the habits of LL district users, which can overlap with the effect induced by the NBS implementation and, thus, by the LL itself, such as improved social attitude and time spent in open space. However, the district scale investigation performed, which was not only in pre-implementation/post-implementation but also in treatment/non-treatment design, and which is reported in detail in D4.8[11], suggests that some beneficial effects to emotional well-being, somatization, self-reported stress, and anxiety symptoms could be attributed to the LLs.

# Annexes 1 – Statistical analysis of the NBS questionnaire for children

**Table 1.** Descriptive analysis on a sample of 15 children attending the 4th grade class (4A).

| | | Age | Female | Male | Pro-environmental attitude | Pro-environmental behaviour | Restoration |
|---|---|---|---|---|---|---|---|
| N (sample size) | T0 | 15 | 5 | 10 | 15 | 15 | / |
| | T1 | 15 | / | / | 15 | / | 15 |
| Mean | T0 | 9 | / | / | 33.733 | 20.266 | / |
| | T1 | 10 | / | / | 33.533 | / | 10.733 |
| Sd | T0 | 0.377 | / | / | 2.374 | 3.091 | / |
| | T1 | 0.457 | / | / | 2.899 | / | 2.250 |

**Table 2.** Repeated Measures ANOVA on a sample of 15 children attending the 4th grade class (4A) with Pro-Environmental Attitude as outcome.

| Effect | DFn | DFd | F | p |
|---|---|---|---|---|
| T0 vs T1 | 1 | 14 | 0.04 | 0.845 |

No significant difference was found between the baseline and the follow-up in pro-environmental levels. NBS intervention did not seem to produce change in this outcome.

**Table 3.** Descriptive analysis on a sample of 23 children attending the 4th grade class (4B).

| | | Age | Female | Male | Pro-environmental attitude | Pro-environmental behaviour | Restoration |
|---|---|---|---|---|---|---|---|
| N (sample size) | T0 | 23 | 11 | 12 | 23 | 23 | / |
| | T1 | 23 | / | / | 23 | 23 | 23 |
| Mean | T0 | 9 | / | / | 32.782 | 21.173 | / |
| | T1 | 10.434 | / | / | 33.913 | 21.956 | 11.318 |
| Sd | T0 | 0.301 | / | / | 2.762 | 3.984 | / |
| | T1 | 0.506 | / | / | 2.661 | 3.226 | 2.056 |

No significant difference was found between T0 and T1 in Pro-Environmental total score and in Pro-Environmental Behaviour in this class (4B).

**Table 4.** Descriptive analysis on a sample of 14 children attending the 5th grade class (5A)

| | | Age | Female | Male | Pro-environmental attitude | Pro-environmental behaviour | Restoration |
|---|---|---|---|---|---|---|---|
| N (sample size) | T0 | 14 | 6 | 8 | 14 | 14 | / |
| | T1 | 14 | / | / | 14 | 14 | 14 |
| Mean | T0 | 9.857 | / | / | 33.714 | 19.500 | / |
| | T1 | 11.214 | / | / | 32.714 | 22.500 | 7 |
| Sd | T0 | 0.363 | / | / | 3.429 | 3.911 | / |
| | T1 | 0.425 | / | / | 1.857 | 3.225 | 2.737 |

No significant difference was found between T0 and T1 in Pro-Environmental Attitude total score while a significant difference were found between T0 and T1 in Pro-Environmental Behaviour total score (T0<T1). In this class, the NBS implementation was successful.

**Table 5.** Descriptive analysis on a sample of 18 children attending the 5th grade class (5B).

| | | Age | Female | Male | Pro-environmental attitude | Pro-environmental behaviour | Restoration |
|---|---|---|---|---|---|---|---|
| | | 18 | 9 | 9 | 18 | 18 | / |
| N (sample size) | T0 | 18 | / | / | 18 | 18 | 18 |
| | T1 | | | | | | |
| | | 9.833 | / | / | 33.888 | 19.277 | / |
| Mean | T0 | 11.294 | / | / | 33.235 | 19 | 7.117 |
| | T1 | | | | | | |
| | | 0.383 | / | / | 3.529 | 4.21 | / |
| Sd | T0 | 0.469 | / | / | 2.773 | 2.449 | 2.595 |
| | T1 | 18 | 9 | 9 | 18 | 18 | / |

No significant difference was found between T0 and T1 in Pro-Environmental Attitude total score and in Pro-Environmental Behaviour score in this class (5B).