European Commission

Implementing green roofs and walls: lessons from European experiences

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2026

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JRC145552

PDF ISBN 978-92-68-37748-2 doi:10.2760/8059292 KJ-01-26-079-EN-N

Luxembourg: Publications Office of the European Union, 2026

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How to cite this report: Enzi, V., Manso, M., Aires, A., Almalla, R., Catalano, C. et al., *Implementing green roofs and walls: lessons from European experiences,* Vierikko, K., Orta-Ortiz, M.S., Nieminen, H., Vasilakopoulos, P. and Velasco Gomez, D.M. (editors), Publications Office of the European Union, Luxembourg, 2026, https://data.europa.eu/doi/10.2760/8059292, JRC145552.

Contents

Abstract

This report is the response to a policy request submitted by DG Environment to the EC Knowledge Centre for Biodiversity (KCBD) through the KCBD ticketing system. KCBD assigned this to the BioAgora project, to be answered by the Science Service for Biodiversity (SSBD).

Green roofs and green walls are proven, scalable solutions for restoring nature in cities, while delivering measurable benefits for climate resilience, biodiversity, energy efficiency, and human well-being. Evidence from case studies across Europe shows that extensive green roofs dominate current implementation, while intensive roofs and vertical greening systems offer higher biodiversity and social value when supported by appropriate design, governance and maintenance. Monitored sites report significant cooling-energy savings, stormwater retention, and support for hundreds of species, particularly pollinators and birds. Results highlight that performance depends on system typology, vegetation diversity, structural complexity, and integration within wider urban green networks, as well as on hybrid governance models combining public leadership with private and community engagement. Participatory approaches, biodiversity monitoring, and multifunctional strategies remain underused but represent major opportunities to increase effectiveness, acceptance, and long-term impact.

This knowledge synthesis report directly supports the implementation of the EU Nature Restoration Regulation and related climate, biodiversity and urban policies, by providing actionable guidance for local authorities and urban planners to meet urban restoration targets through building-integrated greenery.

Foreword

In April 2025, DG Environment submitted a policy request to the Knowledge Centre for Biodiversity (KCBD) through the KCBD ticketing system, for a synthesis of the current state of knowledge on best practice in the design, installation, and maintenance of green roofs/walls for residential and commercial use in Europe. The KCBD assigned this task to the Science Service for Biodiversity (SSBD), which is currently being developed by the BioAgora project. The SSBD is being developed to bridge research outcomes with decision-making needs.

Source: © Stephan Brenneisen.

Acknowledgements

Process Coordination and Facilitation

This knowledge synthesis was coordinated by the BioAgora project, which is funded by the Horizon Europe programme. The request handling and expert coordination were overseen by:

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Coordination Period: 23/04/2025 – 24/02/2026

The focal points served in a coordination and process facilitation capacity, ensuring adherence to ethical standards, facilitating communication between the expert working group and requesters, overseeing the peer review process, and maintaining the integrity of the knowledge synthesis methodology. Their role was specifically designed to support the independence and objectivity of the expert working group while ensuring procedural rigor and transparency.

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Conflicts of Interest and Independence

All expert contributors, methods experts, and focal points completed conflict of interest declarations. The focal points did not contribute to the substantive content of this output to maintain process independence and objectivity, while the methods expert participated as a full member of the expert working group with full intellectual contribution rights. Complete conflict of interest documentation is available upon request.

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The focal point review found no conflicts requiring management beyond disclosure. Panel members bring complementary institutional perspectives - industry association knowledge of market dynamics, municipal implementers' understanding of regulatory contexts, research experience with long-term ecological monitoring, and consulting expertise in practical implementation. These diverse positionalities enriched the synthesis while remaining within appropriate bounds for independent assessment. The panel composition prioritized technical and ecological expertise consistent with the synthesis objectives.

Disclaimer

The views expressed in this output represent the collective assessment of the expert working group based on available evidence. The coordinating focal points and supporting institutions do not endorse specific recommendations but have ensured adherence to transparent and rigorous process standards.

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Executive summary

Policy context

This report is the response to a policy request submitted by DG Environment to the EC Knowledge Centre for Biodiversity (KCBD) through the KCBD ticketing system. KCBD assigned this to the BioAgora project, to be answered by the Science Service for Biodiversity (SSBD). The report supports the Nature Restoration Regulation by showing how building-integrated vegetation systems, such as green roofs and green walls, can help meet urban greening targets. Drawing on experiences from different European climatic regions and prepared by a multidisciplinary team of experts assembled by BioAgora, it offers insights into system types, suitability, installation and maintenance needs. The report highlights governance challenges, economic aspects and key environmental and social benefits. It provides actionable guidance for local authorities and urban planners to support informed decisions and strengthen the installation of green roofs and green walls across the EU.

Key conclusions

This report confirms that green roofs and green walls are strategic nature-based solutions (NbS) that can support cities in delivering multiple objectives under the Nature Restoration Regulation, the EU Biodiversity Strategy, climate adaptation frameworks, and related urban policies. Evidence from European case studies shows that building-integrated greenery can deliver measurable benefits for biodiversity, climate adaptation, stormwater management, energy efficiency and social well-being, validating core assumptions behind current policy approaches. However, implementation across Europe remains uneven, constrained by regulatory fragmentation, financing and maintenance challenges, skills gaps, and limited integration into mainstream planning and building practices.

To address these barriers, the findings point to the need for systematic policy integration, embedding green roofs and walls into spatial planning instruments, and building codes and incentive schemes with biodiversity and climate-resilience criteria.

Figure 1. Noah´s Ark, combining wildflowers and solar panels to a biosolar roof.

Source: © Dusty Gedge.

Policy options emerging from the analysis include strengthening planning and building regulations, introducing targeted incentives and funding schemes, embedding biodiversity-oriented design and monitoring requirements, and promoting multifunctional green roofs and walls that combine greening with renewable energy, water management, and social functions. Performance-based planning tools — such as green space and rainwater management factors, and multifunctionality scoring systems — offer effective mechanisms to guide investment, prioritise co-benefits and support transparent decision-making.

Long-term performance depends on adaptive management, underpinned by biodiversity- oriented maintenance regimes, Internet of Things (IoT)-enabled monitoring and biodiversity tracking, and meaningful citizen and stakeholder engagement. Municipalities play a central role in this transition, requiring strengthened cross-departmental coordination and vertical integration across governance levels.

The report also highlights opportunities for innovation and cross-sector collaboration, particularly through solutions that link energy, water, circular material use and biodiversity objectives, presenting current trends and participatory governance models that can accelerate scaling and cost-effectiveness. Simulation tools and remote sensing data can support decision-making and cost-benefit optimization.

This knowledge synthesis significantly reduces uncertainty by consolidating practical evidence and transferable lessons, providing a stronger basis for informed, action-oriented policymaking giving recommendations on key actions on holistic design, local adaptation, stakeholder engagement, innovation, and knowledge transfer.

1. Introduction

1.1 Background and policy context

European cities face increasing environmental pressures driven by climate change, biodiversity loss, urban densification, and expansion. In this context, building-integrated vegetation systems — particularly green roofs and green walls — are gaining recognition as a valuable category of nature-based solutions (NbS) that can enhance urban resilience, support biodiversity, reduce heat stress, and contribute to more livable urban environments.

A broad set of EU and international policy frameworks converge to support the implementation of green roofs and walls across Europe. At the center of this policy landscape is the Nature Restoration Regulation (NRR), which establishes clear requirements for expanding and improving urban green spaces.

The EU Biodiversity Strategy for 2030 reinforces the need to enhance ecological connectivity and reverse nature loss in cities, goals directly aligned with the habitat provision and pollinator support afforded by vegetated roofs and walls.

Although these systems primarily contribute to the NRR, particularly Article 8 on urban ecosystem restoration, their relevance extends across multiple policy domains, reflecting the inherently cross-cutting nature of building-integrated greenery, for example:

- Energy Efficiency Directive (EED) and Energy Performance of Buildings Directive (EPBD): These frameworks recognize the value of building-integrated and building-adjacent vegetation systems for their local microclimatic effects, such as reducing urban heat islands. They also highlight the direct impact of such systems on building energy efficiency, lowering cooling and heating demand, and welcoming the integration with solar, thereby influencing energy certification processes and the development of a Building Renovation Passport (BRP).
- Urban Wastewater Treatment Directive (UWWTD): This directive emphasizes water-sensitive design at both plot and neighbourhood scales, positioning building-integrated NbS as a key component of wastewater strategies. Such measures provide water purification services, prevent urban flooding through on-site capture, and contribute significantly to the formulation of Urban Wastewater Plans.

Green roofs and walls offer practical, scalable solutions to help cities meet these obligations, especially where ground-level space is limited. Surrounding this core policy (NRR) are several complementary EU strategies and directives that collectively strengthen the case for widespread adoption. Meanwhile, the EU Climate Adaptation Strategy highlights NbS as essential components of resilient urban design, recognising their ability to reduce heat stress, manage intense rainfall, and mitigate flood risks.

In addition to EU legislation, national and municipal initiatives across Europe demonstrate how governance and regulatory innovation can accelerate the implementation of green roofs and green walls. Examples include mandatory green roof and wall requirements in cities such as Basel, Vienna and Berlin, financial incentive schemes at national or regional level, and urban development plans that incorporate ecosystem-service considerations. These policies illustrate the diversity of approaches available to Member States and offer practical models that can be adapted to local contexts.

Taken together, these policies form a multi-layered enabling environment that supports the integration of building-integrated greenery into urban planning and development. This report underscores that green roofs and walls are not only restoration measures but also strategic assets that advance EU ambitions in climate resilience, biodiversity recovery, energy efficiency and public health. This alignment of policies provides a strong foundation for Member States and cities to scale up implementation, ensuring that green infrastructure becomes a standard element of Europe's sustainable and resilient urban future. Further guidance for national stakeholders is both provided and needed, as the overall impact strongly depends on the coherent national adaptation of current policies and regulations, starting with the EED and EPBD (Enzi-Zechner, 2026).

1.2 Purpose of the report

This report has been prepared to synthesize available knowledge and practical experience on the implementation of green roofs and walls across Europe. Its purpose is to inform EU, national and local authorities as they design and implement restoration measures and urban greening strategies aligned with EU policy objectives.

The study was prepared for the European Commission, in collaboration with BioAgora and a multidisciplinary team of experts, including scientists, designers, local authorities and non-profit organisations, ensuring comprehensive practical insights.

The main goals of this report are to assess current practices and experiences with green roofs and walls across different European climatic regions, providing an overview of the different system types, their technical characteristics and suitability for different building contexts (e.g. residential, commercial, new build or retrofit), including their combination with other technical features (e.g. solar panels). Also, it aims to identify key enablers and barriers for implementation related to their installation, maintenance, governance frameworks, and economic viability. In sum, this report synthesizes the lessons learned from European examples to support policy design and practical implementation, giving actionable guidance to local authorities, urban planners and policymakers to support informed decision-making and accelerate the implementation of building-integrated greenery.

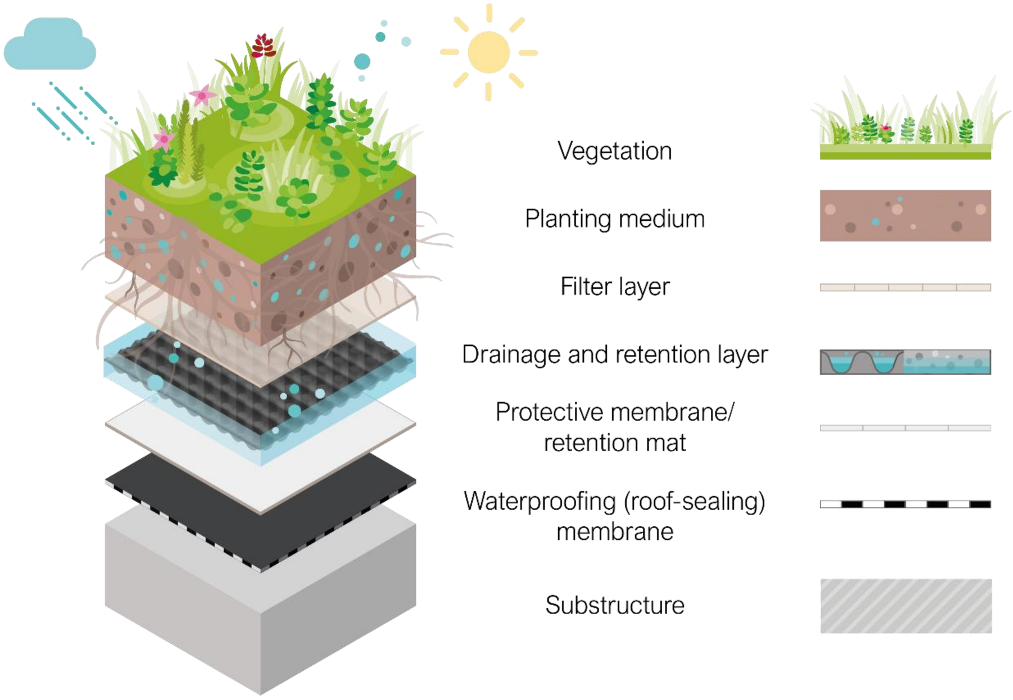
1.3 Problem and significance

The central challenge addressed by this report is the limited and uneven deployment of green roofs and walls across European cities. Although the environmental and social benefits of these systems are well-documented, many cities face gaps in technical knowledge, regulatory support, financing mechanisms, and long-term maintenance planning. Overcoming these barriers is essential for achieving the urban ecosystem restoration targets defined in the NRR and for advancing wider EU climate and biodiversity goals.

2. Green roofs and walls: typologies and technical features

This chapter provides an overview of the main typologies and technical features of green roofs and green walls, establishing a shared understanding of the systems examined throughout the report. It distinguishes between extensive, semi-intensive and intensive green roofs (Fig. 1), and the principal categories of green walls, including the different types of ground-based climbers, planter-based vertical greening and living walls. It highlights their structural characteristics, vegetation types and functional performance. This chapter also outlines key technical considerations such as substrate depth, irrigation needs, structural load, biodiversity value, stormwater retention, shading effects and compatibility with photovoltaic systems. This synthesis supports a practical understanding of how each typology can be applied in different building contexts, whether in new construction or retrofitting scenarios. Each subsection presents also the trends and innovations that shape the future development and application of these systems.

Figure 2. Example of layered green roof buildup.



Source: © Isabel Mühlbauer, Solar Green roofs Resource Guide (Rousset-Rouvière et al., 2025).

2.1 Green roofs

Green roofs are not novel innovations. Their presence can be traced across Europe for centuries. A remarkable example is the Seewasserwerk Moos in Wollishofen, Switzerland, which has sustained a green roof for more than 100 years and today stands as a world-renowned habitat of extraordinary biodiversity. While such historic cases demonstrate the long tradition of vegetated roofs, technology became industrialized in Central Europe during the 1980s, marking the beginning of systematic layered development and widespread application (Fig. 2). Green roofs are also named ‘eco-roofs’, ‘living roofs’, ‘roof gardens’ or ‘vegetated roofs’, and can be defined as rooftops that are partially or completely covered with vegetation (Almalla et al., 2025).

2.1.1 Extensive green roofs

Extensive roofs are relatively lightweight systems designed for broad coverage characterized by low maintenance inputs, shallow substrate depths and low structural load. Minimal depth varies between European countries from as low as 4-5 cm in Scandinavia to more typically 8 cm or 10 - 15 cm in most countries (e.g. Germany, Austria). Generally, a changing climate with more intense summer droughts is driving the required substrate depth up across Europe, as experience is pointing towards a need for increased substrate depths in order to achieve long-term sustainable systems that are able to deliver expected ecosystem services. Extensive green roofs support low-growing plants such as sedums, mosses and grasses, and drought-tolerant wildflowers. They can support biodiversity through the establishment of native species of plants and the creation of microhabitats. These green roofs are highly compatible with solar systems (Photovoltaic and Solar Heat) as their low-growing vegetation does not obscure the solar panels whilst reducing their temperature and thereby helping to improve their efficiency. At the same time, solar panels create shaded habitats. Extensive green roofs can often be retrofitted with innovative solar systems (without changing the green roof) such as bi-facial and flyover solar systems (Fig 3). The relatively low structural loads of extensive green roofs make them ideal for large-area coverage and retrofitting existing flat roofs. Extensive green roofs may have limited accessibility, as they are not usually designed for recreational use. However, they contribute to urban heat mitigation through the reduction of the rooftop surface temperature and retention of stormwater, while absorbing and holding rainwater, and delaying run-off. These systems require minimal maintenance and, in some cases, no irrigation (depending on the local climate conditions and local guidelines and standards), making them the least expensive solution compared to other green roof systems. In warmer climates, with long dry periods, it is recommended to irrigate the green roof during the first two years after installation. (Rousset-Rouviére et al., 2025).

Figure 3. Vertical bifacial panels on an Oslo office building.

Source: Over Easy Solar, Solar Green roofs Resource Guide (Rousset-Rouvière et al., 2025).

2.1.2 Semi-Intensive green roofs

Semi-intensive roofs provide greater design flexibility with intermediate substrate depths (12–30 cm) and plant diversity, including perennials, small shrubs and mixed grassland species. They provide greater ecological and aesthetic value through deeper substrates and tend to feature more diverse plant communities than extensive systems. They can support high biodiversity and remain compatible with solar systems, provided the vegetation height is managed, or an alternative design approach is provided. These systems require moderate structural capacity and are suitable for new construction and selected retrofits featuring full cover or partial cover layouts. Their deeper substrates enable substantial stormwater retention by absorbing rainfall, delaying runoff, and reducing pressure on urban drainage networks. Semi-intensive roofs may require irrigation and will require more maintenance than extensive systems, but they also provide stronger cooling benefits through more evapotranspiration and shading. Depending on the layout, they can include accessible areas that create additional functionality and aesthetic value. They deliver strong microclimate benefits and normally require regular irrigation, particularly in dry periods, to maintain plant health.

2.1.3 Intensive green roofs

Intensive roofs resemble rooftop gardens or parks and are characterised by deep substrates (20cm - 200cm). They offer the highest biodiversity potential through deep substrates that support more vegetation types, including shrubs and also trees. Intensive green roofs are not limited to elevated building surfaces. They can also occur at ground level when constructed over underbuilt structures such as underground garages or basements. In these cases, the vegetated surface is visually indistinguishable from conventional landscaping, and observers may not even recognize it as a green roof. This highlights the versatility of intensive systems, which can seamlessly integrate into urban design while delivering the ecological and climatic benefits of roof greening. Due to their substantial structural load, they are typically feasible only for new buildings, buildings having major structural upgrades, or specific heritage buildings. Intensive roofs provide excellent stormwater management, microclimate cooling, and recreational opportunities, but can require continuous irrigation in summer and frequent maintenance. Their tall vegetation generally limits compatibility with solar systems, although shade structures (pergola type) with solar panels are a solution. Intensive green roofs excel in creating opportunities to provide high-value social and ecological spaces including seating, pathways and recreational spaces (Fig. 4).

Figure 4. Students and staff enjoying the rooftop outdoor study area.

Source: © *Irene Zluwa.*

2.1.4 Recent innovations and trends

Beyond their integration with solar technologies, green roofs are undergoing rapid diversification and innovation. Emerging concepts such as blue-green roofs optimize water retention, storage, and controlled release, transforming rooftops into active components of urban water management (RESILIO Project). In some pioneering cases, green roofs are even designed as roof-based water treatment facilities (Wetland Roofs), providing decentralized purification and flood prevention services (Multisource Project). Latest research trends point towards the functional integration of NbS into the buildings' Heating, Ventilation and Air Conditioning (HVAC) systems, by combining energy recovery measures, pump and Photovoltaic (PV), as well as urine separation on site to provide nutrients for Green Roofs (SAVE Project).

Roofs represent a vast amount of underused space in cities and green roofs can be an alternative to conventional roofs. The multifunctionality of green roofs is increasingly emphasized: they contribute to energy savings through improved insulation and cooling, foster socially inclusive and accessible green spaces, as shown by the European Creative Rooftop Network project (ECRN Project), and support biodiverse green roofs, a new category that prioritizes habitat creation and ecological resilience. Technological advancements are also reshaping the sector, with a strong focus on local and circular materials, particularly innovative substrates that reduce environmental impact while enhancing performance. Together, these trends illustrate how green roofs are evolving from single-purpose installations into complex, multifunctional systems that deliver combined climate, social and ecological benefits (Fig. 5).

Figure 5. Facts values and misconceptions about multifunctional roofs, a clickable infographic.

Source: National Dakenplan, The Netherlands.

2.2 Green walls

Green walls have a long cultural and ecological history. Historic buildings across Europe have often been adorned with climbing plants such as *Hedera helix* (common ivy) and *Parthenocissus tricuspidata*, which provided shade, cooling, and aesthetic value for centuries. These traditional forms of vertical greening demonstrate the enduring role of vegetation in architecture. In contrast, compact, back-ventilated living wall systems represent a relatively recent development. Emerging in the late 20th century, they combine engineered substrates, irrigation, and modular panels to deliver controlled, high-performance greening solutions that extend the possibilities of vertical vegetation far beyond traditional climbers (Fig. 6).

Figure 6. Green wall typologies.

Source: Grünstattgrau; edited by EFB.

2.2.1 Ground-based climbers

Ground-based climbers, also known as green façades, rely on vegetation, mainly climbers, rooted in soil at ground level, which may include self-clinging or have the need of support systems (Fig. 6). Climbers rely on external supports to reach light and space, and their methods of attachment vary widely. The most common strategy is stem twining, where flexible shoots coil around a support; a mechanism found in nearly half of all climbing species. Other plants use tendrils, which are specialized organs that grasp and wrap tightly around structures, or adventitious roots, as seen in ivy, which cling directly to walls.

2.2.1.1 Self-clinging climbers

Self-clinging climbers use tendrils or aerial rootlets (for example, ivy) to provide a simple and low-cost method for greening façades, requiring minimal structural intervention and offering reliable shading benefits that reduce heat stress across the building envelope. They support modest biodiversity due to a narrow species palette (nesting birds, feeding wild bees) but thrive with low irrigation needs or strategic rainwater-intake planning once established. There are evergreen and deciduous climber plant species. Deciduous climbers allow sunlight to reach the façade in winter, supporting passive solar gains, while evergreen climbers provide continuous shading, insulation and visual screening throughout the year. Suitable for most building types and retrofits, these systems produce significant microclimate improvements with low initial investment, although they require suitable façades and periodic maintenance or technical barriers to prevent damage to the building fabric or unwanted spread of growth.

2.2.1.2 Supported climbers

The most common strategy is stem twining, where flexible shoots coil around a support, a mechanism found in nearly half of all climbing species. Other plants use tendrils, but they all need trellises or cable systems (flexible or fixed) to cover large areas of buildings. Support systems expand the range of plant species that can be used and allow for greater biodiversity enhancement. They are suitable for both retrofits and new construction with moderate structural requirements. Adjustments of the distance of the trellis from the wall can provide ventilation, space for nesting birds and prevent damage. These systems improve façade shading, ventilation and local microclimates, while requiring relatively low maintenance. Irrigation needs vary by species and climate but remain modest overall. These factors make supported climbers an option for adding vertical greenery with low impact on building structure and broad design adaptability.

2.2.2 Planter-based vertical green

Planter-based vertical greenery systems consist of modular planters attached to the facade at multiple levels, enabling diverse planting compositions (climbers, shrubs, trees) and contributions to biodiversity (Fig. 6). They impose moderate structural loads and require integrated irrigation systems, making them feasible for both retrofits and new builds with sufficient façade capacity. These systems provide effective shading, cooling and visual enhancement, while offering design versatility, but they require regular maintenance to sustain plant health and system performance. They do not require ground-level space, and this is the strongest argument in dense urban situations.

2.2.3 Living walls

Living walls use prefabricated panels, modules or hydroponic mats and other built-ups attached to the facade as a back-ventilated system, with vegetation rooted within the system to create dense, visually striking greenery with high biodiversity potential (Fig. 6). They offer excellent shading and cooling capacities and contribute significantly to urban microclimate regulation. However, they have higher structural and installation demands, being more suitable for new construction or robust retrofits. These systems have higher costs as they require automated irrigation and more frequent specialised maintenance to support plant growth, offering high ecological and aesthetic value in exchange of higher inputs.

2.2.4 Recent innovations and trends

Recent developments in green wall technologies highlight their potential to deliver both ecological and energy-efficiency benefits. One emerging concept is the bioshading coefficient, a dynamic measure that represents the shading performance of climbing plants or vertical green structures. Unlike static shading devices, the bioshading coefficient changes over time due to the growth behavior of the plants. It accounts for the amount of solar radiation that is blocked by the leaves and the gaps between them, thus influencing the thermal comfort and energy efficiency of buildings (Poiss, 2025).

Green walls can play a meaningful role in urban water management by functioning as nature-based treatment systems for greywater. Scientific evidence shows that well-designed green wall systems can remove key pollutants — such as organic matter (e.g. chemical oxygen demand), suspended solids, and certain nutrients — thereby improving water quality to levels suitable for non-potable reuse. Their performance depends on operational parameters such as hydraulic loading rate, substrate type, plant selection, and climatic conditions (Galvão et al., 2025). EU-funded initiatives (such as NAWAMED, SUPERGREEN, and Multisource Projects) are driving innovation in nature-based wastewater treatment by advancing green wall systems for on-site water treatment and reuse. These systems employ hydroponic, plant-based technologies to treat greywater — and in some cases selected blackwater fractions — enabling its safe reuse for irrigation or toilet flushing. By reducing reliance on potable water, they offer a sustainable solution particularly suited to Mediterranean regions and water-stressed urban environments.

New generations of living wall systems are being designed that allow for the use of local seed mixes. Also, system providers offer to integrate biodiversity supporting elements. This approach enhances biodiversity, supports native species, and strengthens ecological resilience. Furthermore, the integration of greywater reuse concepts into these systems enables irrigation with recycled water, linking vertical greening directly to sustainable urban water management.

Some cities have already integrated green walls into their building plans and other regulatory frameworks, providing specifications for technical details (Green Wall Guideline), monitoring the implementation process over cadastre systems (City of Vienna, Umweltgut Cadastre), and implementing a Green Wall subsidy programme at the same time, as in Vienna. The City of Amsterdam has launched a guideline for Green Wall implementation and keeps a record of projects.

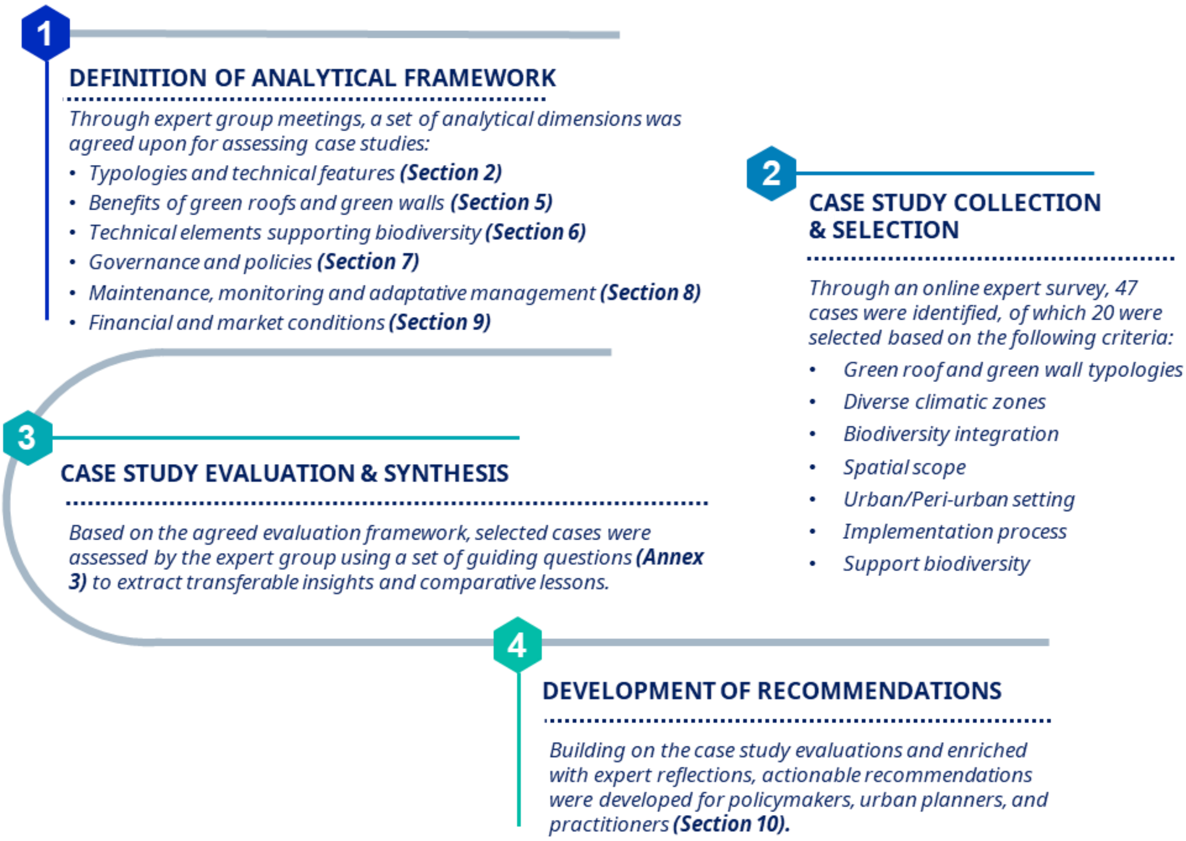
Together, these innovations demonstrate how green walls are evolving into multifunctional infrastructures that combine shading, biodiversity promotion, and circular resource use. In 2021, the first technical standard for vertical greenery ‘ÖNORM L1136’ was published by Austrian Standards International (ASI, 2021), covering greening Objectives, Planning, Installation and Maintenance.

3. Methodology

The methodology followed a four-step, structured approach to ensure robust and policy-relevant insights (Fig. 7). First, an analytical framework was defined, establishing common evaluation dimensions covering green roof and green wall typologies and technical features, ecosystem and biodiversity benefits, governance and policy context, maintenance and adaptive management, and financial and market conditions. Second, existing case studies in European countries were collected and selected through an online expert survey (see Annex 1), identifying 46 cases based on typology, climatic diversity, biodiversity integration, spatial scale, context and implementation process. Subsequently, the 20 most representative case studies were assessed by experts, and they were detailed and analysed using a shared set of guiding questions, enabling the extraction of comparable insights and transferable lessons. This case-based analysis was complemented by expert knowledge and a broad review of additional resources, including scientific publications, technical guidelines, standards and norms, EU-funded projects, policy reports and analytical tools. Finally, the evidence was consolidated into action-oriented recommendations for policymakers, urban planners and practitioners, linking empirical findings with expert reflection to support informed decision-making and effective policy implementation.

A diagram (Fig. 7) summarizes the methodological structure, including the number of case studies, geographic coverage and European climatic conditions (e.g. Continental, Maritime, Mediterranean), and analytical dimensions, with a brief accompanying explanation.

Figure 7. Methodological steps for the report's development.



Through expert group meetings, a set of analytical dimensions was agreed upon for assessing case studies:

- *Typologies and technical features* ***(Section 2)***
- *Benefits of green roofs and green walls* ***(Section 5)***
- *Technical elements supporting biodiversity* ***(Section 6)***
- *Governance and policies* ***(Section 7)***
- *Maintenance, monitoring and adaptative management* ***(Section 8)***
- *Financial and market conditions* ***(Section 9)***

Through an online expert survey, 47 cases were identified, of which 20 were selected based on the following criteria:

- *Green roof and green wall typologies*
- *Diverse climatic zones*
- *Biodiversity integration*
- *Spatial scope*
- *Urban/Peri-urban setting*
- *Implementation process*
- *Support biodiversity*

Based on the agreed evaluation framework, selected cases were assessed by the expert group using a set of guiding questions ***(Annex 3)*** *to extract transferable insights and comparative lessons.*

Building on the case study evaluations and enriched with expert reflections, actionable recommendations were developed for policymakers, urban planners, and practitioners ***(Section 10).***

Source: Own elaboration.

3.1 Case study selection

Several case studies were selected to represent a range of climate zones, policy maturity levels, and strategic biodiversity integration. European cities where green roofs and green walls are embedded in urban planning were prioritized rather than isolated as single initiatives. The case study structure follows a building–neighbourhood–city scale, highlighting ecological connectivity and systemic integration.

The case studies collection resulted from a two-step process. First, a survey was created to identify a first list of case studies based on the experience and expertise of all experts involved in this report. Secondly, the experts contributed to further detail the analytical aspects of these case studies.

In this first step, 46 case studies were identified (see Annex 2) considering their geographical location, the implemented green roof or green wall solutions, their size, the spatial scope (e.g. local/single intervention, neighbourhood, or city scale), and setting of the intervention (e.g. urban or peri-urban).

This initial analysis included an evaluation of the implementation process to determine if these greening solutions resulted from a top-down or bottom-up approach. A top-down approach refers to the implementation of green roofs and green walls that results from the decision of authorities or experts. A bottom-up approach would include local stakeholders, such as building users, residents and local communities, to determine their needs, insights and participation, to define the project outcome. Also, a close-ended question determined whether the case studies involved a participatory process or not. This question enabled to understand if there are collaborative approaches between authorities, experts and community stakeholders to implement green roofs and green walls in European cities. Finally, a close-ended question was included to determine if there were any design features or monitoring efforts to support or assess biodiversity outcomes after implementation. This aspect was considered important to enable the identification of case studies that would promote biodiversity in urban contexts.

In the second step, the involved experts selected 20 of the previous case studies (see Annex 2) to describe in detail the green roofs and green walls technical features, their environmental/ecological, social and economic benefits, their governance and implementation challenges, their maintenance and monitoring, and finally the financial and market conditions that influence their viability. To guide these analyses a list of questions was created to further guide the experts on the purpose of each analytical element. The analyzed case studies are further described in sections 4 to 8, considering the most relevant analytical elements detailed in the analysis.

During the analysis on aspects regarding municipalities and planners, best practices of related resources and tools, and research projects, have been recorded and cited in the report.

4. Case studies analysis

The survey identified 46 case studies, with a strong predominance of green roofs over green walls (Annex 2). Extensive green roofs are the most common type (16 cases), followed by semi-intensive and intensive systems (11 each). In contrast, ground-based climbers and planter-based vertical green systems are each represented by only one case, while living walls account for seven examples.

The case studies are distributed across 14 European countries, showing strong regional clustering in Central, Western, and Southern Europe (Fig. 8). The geographical distribution highlights where implementation is most active and where supportive policy, market maturity, and research ecosystems are strongest. The underrepresentation of Eastern Europe suggests opportunities for policy support.

Figure 8. Geographical distribution of case studies.

Source: Mapchart.net, own elaboration (16.02.2026).

Approximately one third of the case studies (17 of 46) incorporated design features or monitoring actions to support biodiversity. This finding is significant as it shows a recognition of the ecological role of green roofs and green walls in European practice. It also illustrates the alignment with EU ecological restoration objectives, including the NRR, climate adaptation strategies and biodiversity monitoring initiatives. These design features and monitoring actions will be further described in the report.

Most interventions were implemented as local or single-site projects (35 cases), with fewer examples at the neighbourhood scale (11) and only one at the city scale. This indicates that the implementation of green roofs and green walls is largely pursued through project-based initiatives rather than strategic, city-wide programmes. Scaling-up remains limited, suggesting the need for stronger municipal policies, incentives, and integrated planning frameworks to achieve broader urban ecosystem impacts.

Most case studies are in urban settings (37 cases), with 10 in peri-urban areas. This reflects the intention to use green roofs and green walls as solutions to urban environmental challenges: heat islands, dense built form, limited ground space, and stormwater management.

The survey reveals a heterogeneous landscape of implementation approaches, with 11 top-down, 8 bottom-up and 12 hybrid cases, while many remain undocumented. This diversity indicates that no single governance model dominates green roof and green wall deployment in Europe, reflecting variations in local policies, markets and institutional cultures. Top-down approaches — often linked to municipal regulations and climate or biodiversity strategies — enable scaling, standardisation and long-term maintenance. Bottom-up initiatives, typically driven by communities, NGOs or research organisations, emphasise experimentation and local needs, but may struggle with sustained stewardship. The strong presence of hybrid models highlights the growing importance of co-governance, combining authority-led strategies with local engagement and shared ownership. However, the high number of "unknown" cases points to a documentation gap, underscoring the need for clearer reporting standards in urban greening projects.

In fact, while 17 case studies incorporate participatory processes which may include co-design, citizen-science monitoring, or community involvement, many others lack documented engagement. This uneven integration of participatory processes suggests that social involvement is still not systematically embedded, even though it can strengthen project acceptance, ecological monitoring and long-term success, highlighting a clear opportunity to improve practice across future implementations of green roofs and green walls.

5. Benefits of green roofs and green walls

Under different climatic conditions, green roofs and green walls are considered a potential solution to address the adverse impacts of climate change and urbanization, and are increasingly used to achieve environmental, social, economic and ecological benefits. Scholars have usually focused on the beneficial aspects of green roofs and green walls highlighting their significant roles in climate change adaptation and mitigation as well as in improving the quality of built environment. Among other benefits, green roofs and green walls when integrated with other NbS, can contribute to urban biodiversity enhancement, manage urban stormwater, reduce urban temperature, regulate the microclimate, and provide benefits for human health and well-being (Manso et al., 2021; Almalla et al., 2025). However, the benefits provided by these greening systems can vary largely according to the plant types, the system characteristics, age, as well as climate conditions.

5.1 Biodiversity metrics/outcomes

The loss of biodiversity in an urban area is a big concern among environmental scientists. Green roofs and green walls can enhance biodiversity by providing habitat for urban dwelling fauna and mimicking nature. However, evidence for their role in attracting and promoting biodiversity is not widely discussed in literature. Additionally, the selection of plants for green roofs and green walls on buildings is crucial and can be complex, as many factors need to be considered regarding the building itself and the surrounding environment, as well as the flora and fauna.

Green roofs' substrate thickness and grain size distribution are the most significant factors influencing the species richness (alpha-diversity). Thus, intensive and semi-intensive green roofs are richer than extensive green roofs, especially when left to spontaneous colonisation (Muratet et al., 2024). Deeper substrates in fact enable a better root growth, a higher plant resources availability, a higher total water storage, and reduce the effect of daily climatic fluctuations. Importantly, the relationship is not linear, thus after a minimum of about 13 cm thickness, species diversity is less influenced by further increase in substrate thickness (Muratet et al., 2024).

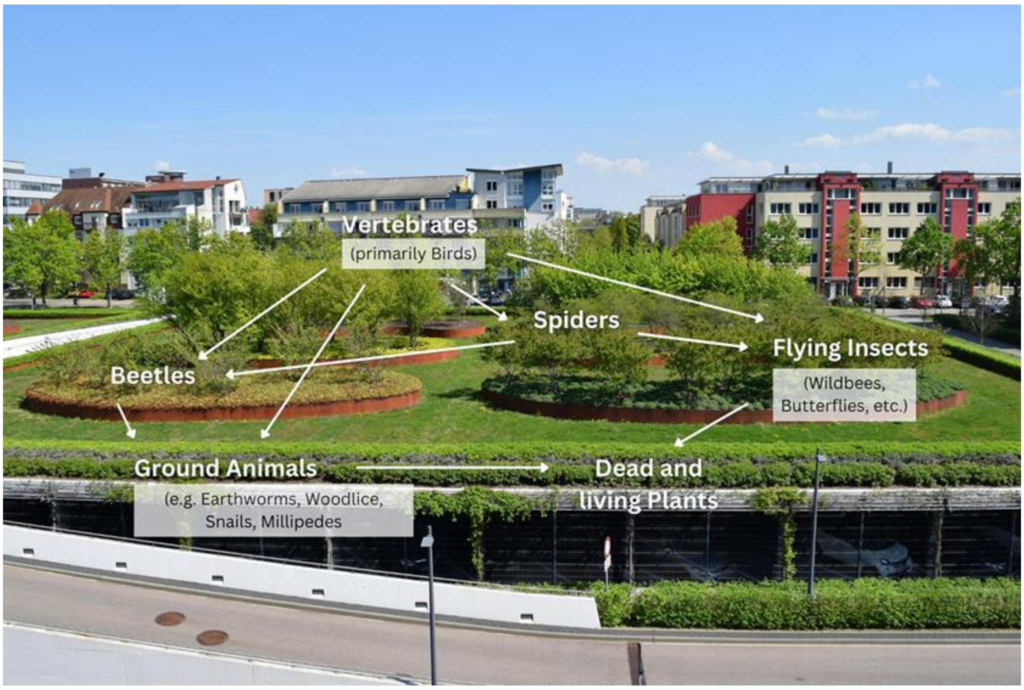
Generally, thicker substrate layers contribute to increased biodiversity potential and species cover, while providing also other benefits such as stormwater management and improved heat island mitigation. Nevertheless, research shows that despite the reduced species cover, green roofs subjected to more extreme abiotic conditions, e.g. increased drought, or sun exposure, have a potential to support more rare and even endangered species (Lönnqvist et al., 2021; Muratet et al., 2024). These urban biotopes can be resilient and last over 100 years, offering unique opportunities for biodiversity conservation within cities, thus reducing the impact of urban development on ecosystems and their services (Landolt et al., 2000). Besides substrate thickness, the substrate structure is also relevant for biodiversity enhancement. Recent research indicates that high plant diversity can be supported on compositions of about 20% sand, 20% clay, 60% silt (Muratet et al., 2024). Still, technical requirements for permeability and substrate stability might sometimes limit the use of fine particles in extensive green roof buildups (e.g. Research Society for Landscape Development and Landscape Construction – FLL Guidelines).

Together with substrate structure, time is one of the most important factors influencing biodiversity (in terms of species richness). In general, old roofs have a higher biodiversity than newly created ones, until a certain limit when species colonisation is slower than local species extinction (Catalano et al., 2016; Muratet et al., 2024), a mechanism which is significantly evident on extensive green roofs, due to the harsher conditions. These roofs may still provide important functions, such as nesting habitat for invertebrates and shelter in extreme heat conditions.

Considering spontaneous colonising plants, taxonomic, functional and phylogenetic diversity increase along with substrate thickness and nutrient content (Barra and Johan, 2022). Meanwhile, structural plant diversity provided by different plant growth forms (namely plant functional diversity) and biomass are the most important factors influencing arthropod species richness (Madre et al., 2013). Also, higher plant richness can support a richer biocoenosis (Coulibaly et al., 2023). Nevertheless, it is also notable that roofs located in greener areas (surrounded by a higher proportion of green spaces) have higher species richness, regardless of the type of green roof (Aloisio et al., 2020). Intentionally introduced species can also influence positively species richness (Muratet et al., 2024), serving as nursery for spontaneously colonising plants (e.g. by protecting seedlings from extreme conditions).

Green roofs act as urban stepping-stone habitats, supporting pollinators, birds, and even rare plants over time. Extensive roofs mainly attract flying insects like bees, butterflies, and hoverflies, while intensive roofs host higher species richness, including beetles and wild bees (Fig. 9). Studies report up to 236 wild bee species on green roofs, with diversity strongly linked to substrate depth (≥15 cm), structural heterogeneity, and forage availability. Older roofs can harbour over 175 plant species, including orchids, and more than 300 beetle species, some on Red Lists. Bird species such as sparrows, blackbirds, and even crested larks use roofs for foraging and nesting. Biodiversity tends to increase initially and stabilize over time, with targeted maintenance and native plant use enhancing long-term ecological value (EFB, 2025). Also, a recent study report that green roofs serve as vital hubs for a wide variety of fungal diversity within urban environments. A study performed in three different metropolitan areas in USA examined 44 different green roofs and compared the results with the surrounding environments. Results demonstrated correlation between fungal diversity and increased plant cover both in intensive and extensive green roofs (Droz et al., 2022).

Figure 9. Different green roof habitats.



Source: BuGG, edited by EFB.

Pollination is relevant for gene flow among populations, which increases community resilience (Ksiazek-Mikenas et al., 2019). To increase genetic diversity, it is suggested to use plants propagated from seeds collected in natural stands, or from more than one nursery. Also, planting large populations of self-compatible species can reduce the risk of inbreeding depression, by reducing the mating chance of closely related individuals. It was also found that green roofs constitute suitable habitat for ground nesting wild bees, regardless of roof characteristics such as age, abundance and species richness (Jacobs et al., 2023), and that pollinator visits are influenced by building height and flowering time (Underwood et al., 2025). Plant community, flowering period timing and length (phenology) influence foraging opportunities, which is relevant for pollinators' visits and diversity (Guidi et al., 2024). In fact, the same species tend to flower earlier on roofs than on the ground, offering a unique opportunity for pollinators relying exclusively on urban resources (Fig. 10).

Wooster et al. (2022) provided a unique case study that clearly demonstrates the potential for green roofs to promote biodiversity in urban spaces. The green roof within the study supported four times the avian and over seven times the arthropod diversity of the traditional roof, as well as providing a gastropod habitat, not present on the traditional roof. The roles of pollinators have been also discussed in the literature. For example, in the study by Wooster et al. (2022), different group of plants were planted to attract a range of pollinators to the green roof, resulting in attracting a high level of arthropod diversity.

Figure 10. Flowers pollination, Postverteilerzentrum Vienna.

Source: © Elisabeth Weiss-Tessbach.

Vertical greenery provides habitat and food for various species, especially evergreen climbers like ivy. Ivy offers nectar and pollen for bees, wasps, hoverflies, and spiders, while its fruits feed birds such as robins and thrushes. It also serves as nesting site for species like blackbirds and wrens. Recent surveys in Vienna found 32 wild bee species on 14 green walls, with hotspots linked to flowering plants like Nepeta and Sedum (Lanner, 2022). Green walls can also support bats and insects like moths (Hengsberger, 2022), contributing to ecological connectivity in dense urban areas. System designs increasingly integrate nesting elements to boost biodiversity, making façades valuable microhabitats in cities.

A study by Hecht et al. (2025) demonstrated that green façades and living walls can function as effective urban habitats, particularly for insects and other climbing or flying species. Monitoring of different green walls in Singapore recorded interactions with 280 animal species, dominated by insects, and showed that biodiversity increased significantly when trees were present within 10 m, acting as ecological stepping stones. Species richness and abundance were positively linked to vegetation thickness and plant diversity, indicating that structurally complex and well-connected green walls provide higher-quality habitats. These findings highlight the importance of integrating Vertical Greenery Systems (VGS) into wider urban green networks, and adopting biodiversity-oriented design and maintenance practices to maximise their ecological value.

Knowledge on green walls' biodiversity potential is still recent. Therefore, further studies are needed.

5.2 Stormwater management

Stormwater runoff has become an increasing challenge in urban areas due to the widespread use of impermeable surfaces that lack water retention capacity. As a result, rainfall is rapidly conveyed into sewer systems, which can become overloaded during intense precipitation events, leading to flooding, particularly in low-lying urban areas.

In urban areas, especially those under threat of flooding and increased urban runoff, green roofs can play an important role in managing urban stormwater by retaining and detaining rainwater, thereby reducing runoff volumes and peak flows. Their effectiveness in stormwater management depends on the system characteristics (e.g. substrate depth and composition, roof age, slope, pore volume, saturation level, plant selection, plant density and composition, above-ground plant structures, and drainage layer design; Manso et al., 2021) and local climate conditions (e.g. seasonal variations, volume and intensity of rainfall). For example, in northern Europe and cold regions there are seasonal variations in green roof-based stormwater retention, particularly due to a reduced infiltration capacity associated with soil frost and snow cover (Almalla et al., 2025). In sum, green roof substrate and vegetation play a key role in stormwater management. The substrate retains rainfall until its saturation; on site, this timely delay is important for managing heavy rain events. Therefore, intensive green roofs can retain more rainwater than extensive ones. Besides, vegetation type and above-ground plant structures further influence water interception and retention.

Extensive roofs typically retain 50–80% of annual precipitation, depending on substrate depth, vegetation type, and climate. Intensive roofs, with deeper substrates, can achieve even higher retention rates. Studies on the retention capacity of intensive green roofs demonstrated that the rate of rainwater reduction can reach up to 85% (GMCA, 2020; Kandel and Frantzeskaki, 2024). During heavy rain events, green roofs slow peak runoff by up to 90%, reducing pressure on urban drainage systems. Besides, seasonal variation matters, as water retention is highest in summer, due to evapotranspiration, and lowest in winter. Studies show that a 10 cm substrate can store 30–40 liters per m^2, while a 15–20 cm substrate can exceed 50 liters per m^2. Therefore, combining green roofs with smart irrigation and monitoring systems further optimizes stormwater performance (EFB, 2025).

Urban stormwater often contains pollutants and heavy metals originating from atmospheric deposition and urban surfaces. Green roofs and green walls can help mitigate this pollution by retaining and filtering contaminants through their substrate and vegetation layers. Their filtration capacity enables the capture of both soluble and insoluble metal particles, reducing pollutant loads in runoff. These processes ultimately contribute to improved urban stormwater quality and support more sustainable water management in cities. When green roofs and green walls are implemented, total suspended solids (TSS) decrease. As an example, Kandel and Frantzeskaki (2024) found that extensive green roofs removed 79-97% of TSS in a temperate climate. Also, Galvão et al. (2022) tested a living wall using different recycled substrates and determined that a mix of crushed tiles and coconut fibres can remove 59–70% of TSS.

Even in warmer climates, green roofs can be an effective strategy to reduce stormwater runoff and peak flows at both individual building scale and across an urban catchment. Andrés-Doménech et al. (2018) performed a study in Benaguasil, in the region of Valencia, Spain, where they combined a detailed monitoring of experimental green roofs with hydrological modelling to simulate different green roof coverage scenarios over a real city drainage network. Results indicate that green roofs can substantially attenuate runoff volume and peak discharge during frequent, small to medium storm events, while their relative effectiveness decreases for very intense storms, emphasizing their role as a complementary measure for urban flood mitigation. In the literature, several methods have been used to study the hydrological performance of green roofs. Among other methods, SWMS-2D, HYDRUS, and other models are shown to be effective for measuring the reduction rate of urban runoff in the green roof's structure.

The concept of the blue-green roof is emerging to emphasize the stormwater retention capabilities of green roof systems. With a water storage layer underneath the layered green roof system, substantial stormwater can be retained. The added micro water management system aligns with the concepts of a 'sponge city' and polder roofing. By combining extensive green roofs with sub-substrate water storage and a smart outflow, the efficiency of the green roof can be improved even under extreme precipitation events. Additionally, the evaporative cooling increases and plant stress is reduced. A study showed that blue-green roofs can capture 70-97% of extreme precipitation (>20 mm/h) when set to anticipate ensemble precipitation forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) (Busker, 2022). Moreover, blue-green roofs allow for high evapotranspiration rates relative to potential evapotranspiration in hot summer days (around 70%), which is higher than from conventional green roofs (30%) (Busker, 2022).

5.3 Urban cooling and microclimate regulation

European cities are increasingly experiencing high temperatures during the summer months, a trend expected to intensify as climate change will lead to higher maximum air temperatures in the future. Dense urban areas are particularly affected by the Urban Heat Island Effect (UHIE), a phenomenon in which temperatures in cities are higher than in surrounding rural areas due to factors such as high surface temperatures, air pollution, limited vegetation, building morphology, and reduced evaporative cooling. This effect negatively influences thermal comfort and public health while increasing energy demand for cooling in buildings. The study *Urban Cooling Demand in Austria 2030/2050* provides a systematic analysis of the increasing demand for cooling and its geographical distribution across Austria (Wimmer et al., 2025). The results offer valuable insights into current and future cooling needs and support evidence-based decision-making for the development of climate protection and climate change adaptation strategies.

In response to these challenges, nature-based solutions such as green roofs have gained attention as an effective strategy for urban climate adaptation. A substantial body of research demonstrates that green roofs can mitigate urban heat by lowering roof surface temperatures and reducing surrounding air temperatures. These cooling benefits are mainly achieved through vegetation shading, evapotranspiration, and improved thermal insulation, which collectively help regulate urban microclimates and reduce heat stress in densely built environments. A review evidences that green roofs can reduce the surrounding temperature by 1.34°C, with reductions typically ranging between 1°C and 2.3°C depending on climatic and design conditions (Manso et al., 2021).

Green roofs and green walls also have the potential to enhance building energy efficiency. Their performance depends on a combination of factors, including system characteristics — such as leaf area, geometry, substrate type and depth, moisture content, layer composition and integration with the building — alongside building physical features, including height, insulation level, construction materials, envelope design, glazing ratio, solar orientation and shading. Local climate conditions, as well as seasonal variations and heating or cooling demands further influence their overall energy performance. Overall, the highest energy savings are observed when intensive green roofs are compared with conventional black roofs, particularly on non-insulated buildings, where reductions of up to 84% in cooling energy demand and 48% in heating energy demand have been reported (Manso et al., 2021).

The cooling behaviour and impact of green roofs have been widely studied and their role in regulating microclimate by providing thermal comfort and reducing surface temperatures has been demonstrated in many studies globally. For example, a study conducted by Feng et al. (2022) highlighted the significant cooling effect of green roofs under extreme heat conditions, with around 6% reduction in energy use through improved insulation and cooling (GMCA, 2020). Through the evapotranspiration provided by the plants and direct evaporation from the retained water in the soil layer, green roofs play an important role in reducing the temperature of the buildings and its surrounding environment. However, in terms of strategies to improve microclimate in urban areas, most studies have focused on the cooling effect of green spaces on the ground level, such as parks and gardens, which reduce air and surface temperatures. Only few studies have considered the implementation of vegetation into the building envelope as another strategy to mitigate high temperatures in cities (Almalla and Di Marino, 2025). Assessing the cooling benefits of green roofs relies on a set of climatic indicators and diverse data sources. The three-dimensional microclimatic modelling ENVI-met is the most common method and has been extensively used, due to its capability to consider the climatic variables that influence cooling benefits on the microclimate level and thermal comfort scores.

Biotope City Wienerberg (Box 1) demonstrated how embedding green infrastructure and microclimatic criteria (for example over a Green Blue Factor - GBF) in early planning phases can actively shape microclimatic conditions of city quarters through NbS (Reinwald, 2021). The district integrates extensive green roofs, façade greening, and diverse vegetation structures, resulting in measurable climate benefits. Simulation-based assessments using ENVI-met showed, besides other benefit factors, up to 22.3°C Physiological Equivalent Temperature (PET)[1], and an improvement of human thermal comfort, compared to conventional designs (OPPLA, 2025).

Box 1. Biotope City Wienerberg - Vienna, Austria.

Impact: 5.4 hectare transformation area of former Coca Cola production site, neighbourhood with 990 apartments, 2/3 social housing. Large-scale integration of green roofs/walls (13,600 m² green roofs, 2,200 m² green walls), biodiversity concept, and social housing benefits.

Challenges: Circular construction efforts and rainwater reuse faced regulatory complexity.

Success Factors: Holistic planning, performance simulation (Green Pass), and multistakeholder cooperation (Municipality-Research-Industry).

Policy Influence: Model for the 'Green & Open Space Factor'/GBF in Vienna's planning. End Report and Handbook for Biotope Cities (Reinwald, 2021). Replication advice Biotope City Journal (Fassbinder, 2024)

View from a rooftop, Biotope City Vienna, © GreenPass

Cirkel et al. (2018) discussed a field campaign conducted in Amsterdam, the Netherlands, on three plots from May 2017 to May 2018 to evaluate the water and energy balance of conventional and novel blue-green roofs as a climate adaptation measure in urban areas. The study showed that conventional extensive green roofs, typically covered with Sedum on shallow substrates, experienced low evaporation rates and minimal cooling effects due to rapid moisture decline. Meanwhile, blue-green roofs with a storage and capillary irrigation system exhibited remarkably large evaporation rates, especially with grass and herbs cover, and significantly reduced the occurrence of dry-out events, suggesting improved cooling efficiency in cities. The study directly addressed the challenge of urban cooling by providing valuable quantitative data and model predictions on how different green roof types provided water and energy balance to regulate the microclimate through enhanced evaporative cooling. However, the results also highlighted the

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[1] PET is the air temperature in a simple indoor reference environment (no wind, no solar radiation) that would produce the same thermal comfort as the actual outdoor conditions. It is widely used to assess heat stress, urban climate, and thermal comfort in urban planning. PET can differ from real air temperature by more than 20 K in extreme heat.

importance of local microclimatic conditions, such as wind speed and anthropogenic sources of energy, when estimating the cooling effect of green roofs.

Box 2. MA48 Green Wall - Vienna, Austria.

Impact: 850 m^2 of Living Wall on a municipality building as a monitored pilot installation, installed in 2010. Significant cooling effect (evaporating 1.600 l/day on a hot summer day), biodiversity spot (wild bees, butterflies), and energy savings (50% less winter heat loss compared to before).

Challenges: Initial regulatory hurdles (air tax, fire safety), technical risks (sensor failure) and lack of rainwater harvesting options.

Success Factors: Strong multistakeholder cooperation, IoT-based irrigation, and adaptive management.

Policy Influence: Led to the Austrian green wall standard and guidelines, fire safety codes and subsidy programs.

Pilot Green wall on MA48 (© Vera Enzi)

An investigated living wall in Vienna provided clear benefits compared to a plaster façade, improving both building performance and the immediate environment (Box 2). Air temperatures behind the living wall were up to 8.79°C cooler in summer and 6.81°C warmer in winter, with corresponding reductions in wall temperature and heat flux that enhanced thermal stability. Daily fluctuations in temperature, humidity and heat transfer were significantly attenuated, while concerns about wall damage from condensation or humidity were not substantiated. Although wind made wider environmental effects harder to measure, correlations in relative humidity and thermal imaging confirmed positive impacts from evapotranspiration and reduced sensible heat emissions: 850 m^2 of wall evaporated 1.600 l/per summer day. Overall, the living wall contributed to improved thermal comfort and associated health benefits (Scharf, 2013).

5.4 Social and health co-benefits

Climate change effects are tightly interlinked with Human Health and Well-being (HH&W). Rising urban temperatures and more frequent heatwaves cause negative impacts on human health, aggravating diseases, and elevating the risk of hospitalization and mortality. Green roofs and green walls are considered robust solutions to reduce temperatures and associated health risks. Like other environmental concepts, HH&W is difficult to define and measure because it is linked to the human body's feelings. Nevertheless, researchers have investigated HH&W via questionnaire surveys and interviews in different residential areas and neighbourhoods. These greening systems can enhance HH&W by reducing air temperature and improve air quality. Green roofs as an alternative solution to traditional roofs create and offer attractive spaces that add aesthetical value for building users.

Outdoor vegetated systems contribute to physical and mental health by contributing to decreasing urban temperature and improving air quality, while absorbing noise. Also, they create restorative environments that contribute to citizens' well-being. Green roofs and walls help mitigate urban heat stress - which is linked to cardiovascular and respiratory risks - by cooling surfaces and the surrounding environment. Also, they filter particulate matter and pollutants, supporting respiratory health. Therefore, these greening systems indirectly reduce heat-related mortality. Visual access to greenery, even when implemented on rooftops or façades, has been shown to reduce stress, enhance mood, and improve cognitive performance. Studies also suggest that the proximity to green roofs and green walls can increase outdoor activity and social interaction, foster community well-being and improving overall urban liveability.

To better understand the role of green roofs in dense urban areas in providing social and health co-benefits, Mesimäki et al. (2019) conducted a quantitative study examining the experiential potential of a small urban green roof. Using a questionnaire survey, they explored restorative and other experiences among 178 visitors to a sparsely vegetated green roof in the centre of Helsinki, Finland. This study showed that even a small and sparsely vegetated green roof located between buildings in an urban area can provide various types of recreational and experiential benefits.

Additionally, a study by Matos Silva et al. (2023) examines how people perceive the ecosystem services of urban green roofs and how these perceptions relate to indicators of psychological restoration and well-being. The results of a cross-sectional survey of 376 green roof users showed that users who attributed higher social and cultural services to the green roof, such as opportunities for social interaction, feeling part of a community, and enjoying the presence of others, also reported stronger restorative experiences and better self-rated well-being, indicating that social interaction on green roofs is a key pathway through which these spaces support citizens' psychological health.

The restorative potential of living walls in public spaces was analysed by Molari et al. (2024) who conducted a survey at two different sites: one at the Cultural Center of Belém (CCB) in Lisbon, Portugal (Box 3), and the other at Complesso Aldo Moro in the historic centre of Turin, Italy. This study examined how green walls influence users' cognitive perception and well-being, drawing on the principles of Attention Restoration Theory. The findings reinforced the strong connection between citizens' aesthetic appreciation of living walls and their perceived sense of comfort, relaxation and mental restoration. Observations of spontaneous social gatherings and resting behaviour near both installations further demonstrated the attractiveness of these NbS as urban landmarks that enhance public space quality.

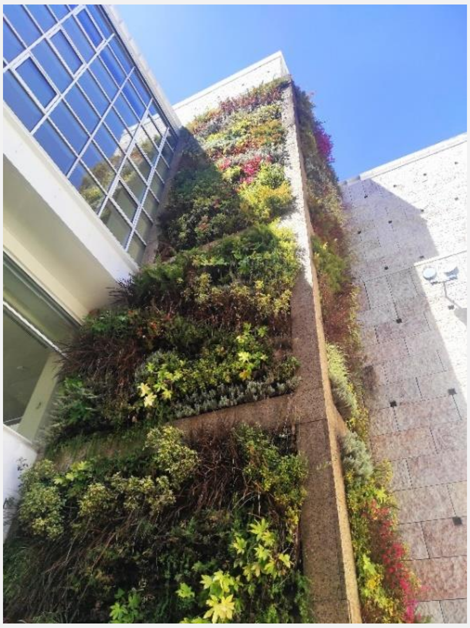
Box 3. Centro Cultural de Belém - Lisbon, Portugal.

Impact: Two living walls with a total of 250 m^2 placed at the entrance of CCB, the museum of modern art, highlight the socio-cultural implications of urban greening.

Challenges: A mixed method consisting of on-site inspections, including naturalistic observation, and a survey using the perceived restorative scale (PRS) of green walls. A self-rating assessment enabled to define the sense of relief and restoration perceived by users in response to a green environment.

Success Factors: Research findings demonstrate high level of interactions with the green walls and creating opportunities for recreational use of the surrounding outdoor environment.

Policy Influence: Included a cost-benefit analysis of the Living Wall system as part of Lisbon Green Capital in 2020, which reinforced contributions in increasing green areas in the urban environment. Its potential for social interactions and promoting users' well-being was assessed by researchers.



Living wall, CCB (© Maria Manso)

As part of Helsinki's anti-segregation and environmental justice policy and the Think Nature project, 'The Greenest of the Green' became an example that promotes citizens well-being (Box 4). It comprises a newly built social housing complex, with 121 dwellings, in the densely built coastal district of Jätkäsaari, Helsinki. The site is highly exposed to Baltic Sea winds and solar radiation, with no tall surrounding trees. The project aims to create a green and biodiverse living environment by adding green roofs and walls to the envelope. It places particular emphasis on the health and well-being of residents. In a very densely built district with long-term construction works and limited nearby green areas, the green roofs and walls provide everyday access to nature, gardening and outdoor shared spaces to residents. These shared green spaces strengthen social cohesion and sense of community within the block, support residents' environmental responsibility and pro-environmental behaviour, and contribute to well-being by offering stress relief and restorative nature experiences in a dense urban environment. This project demonstrates that it is possible to combine different tenures (private ownership, rental, and supported housing) while ensuring that vulnerable groups benefit from high-quality green amenities, even within standard Finnish social-housing cost limits.

Box 4. The Greenest on the Green - Jätkäsaari, Helsinki, Finland.

Impact: Intervention in the 121 social housing blocks at the Jätkäsaari district including two meadow roofs to support biodiversity and green façades together with other greening strategies. Successful establishment of many plant species (70%) in the harsh environmental conditions (wind, sun) of the Nordic climate.

Challenges: promoting biodiversity in the harsh environmental conditions (wind, sun) of the Nordic climate.

Success Factors: Collaboration between researchers, community engagement (housing residents) and a private greenery service company to design, install and maintain experimental planter-based vertical greening.

Policy Influence: Part of Helsinki's anti-segregation and environmental justice policy, including private ownership, rental and supported housing, while ensuring vulnerable groups also benefit from high-quality green amenities.

Greenest of the Green (© Taina Suonio)

5.5 Energy efficiency and life span

Green roofs and walls deliver synergistic benefits for buildings and cities. Over the past decade, a growing body of research has demonstrated the significant potential of green roofs and green walls to enhance the energy efficiency of buildings. Their performance depends on multiple interacting factors, including system characteristics — such as leaf area, geometry, substrate type and depth, moisture content, layer composition and the degree of integration with the building envelope, as well as building-specific features, including height, insulation levels, construction materials, glazing ratio, orientation and shading conditions. Local climate conditions, seasonal variations and heating or cooling demands further influence energy outcomes (Manso et al., 2021).

Recent studies have been focusing on demonstrating how green roofs and green walls can contribute to reduce buildings' energy demand and improve their thermal performance. By moderating surface temperatures and reducing heat flux, green roofs can lower cooling demand in the summer by up to 84% and heating demand in the winter by 8-10%, depending on substrate depth and design (Zirkelbach, 2013). Considering the high number of studies in this field it is now possible to estimate average U-values (thermal transmittance) for these greening systems. A comprehensive review of the thermal characteristics of green roofs and green walls further explains how the vegetation and substrate layers, air gap (between the system and the building envelope), and moisture presence can influence their thermal performance (Harbiankova and Manso, 2025).

Also, this thermal buffering not only improves indoor comfort but also extends waterproofing life by 10–20 years in comparison to conventional flat roof systems, reducing maintenance cycles and insurance risks, for example providing hail protection. Green roofs and walls do not have a fixed 'end-of-life' timespan; their longevity depends on the durability of the chosen system and the quality of maintenance. Well-designed projects have demonstrated that such solutions can remain functional and effective for decades, with historic examples proving their resilience over time. Green roof systems act as a protection of the waterproof membrane from direct exposure to solar ultraviolet radiation and help limit diurnal temperature fluctuations on the building envelope (Cascone, 2019).

A highlighted case study shows that a 5,000 m² multifunctional green roof saved approximately €6,000 annually in electricity costs through combined effects of rainwater harvesting and cooling (Dörries and Zens, 2003). Such savings are amplified when integrated with biosolar systems, where PV efficiency can increase by 4–8% due to evaporative cooling.

These combined benefits - energy savings, reduced urban heat island effect, stormwater retention, and biodiversity - make green roofs and walls a competitive investment, especially in dense urban areas. They support climate adaptation, enhance resilience, and contribute to long-term cost efficiency and sustainability (EFB, 2025).

5.6 Long-term economic returns

Green roofs and walls deliver measurable financial and societal value over their life cycle. Beyond direct energy savings and extended membrane life, these systems generate, like other NbS, Social Return on Investment (SROI) by reducing urban heat stress, improving health and well-being, and enhancing biodiversity. These benefits translate into avoided public costs and increased property value. The methodological development in this specific area is currently evolving (Vasiliu, 2024).

Impact investors increasingly recognize vegetated infrastructure as a NbS aligned with Environmental, Social, and Governance (ESG) goals, offering both financial returns and quantifiable social and environmental impact. When site-specific lifecycle benefits, such as stormwater fee reductions, energy cost savings, carbon storage, and deferred maintenance are monetized, green roofs and walls can outperform conventional approaches in total value creation. This positions them as strategic assets for impact-driven portfolios, urban resilience planning, and sustainable real estate development.

The growing interest in Public-Private Partnerships, Green Impact Bonds, and performance-based investments that integrate NbS is encouraging (ImpaQt project). However, financial institutions remain cautious, as concerns about potential greenwashing persist and standardized performance metrics have not yet been established. As a result, benefits and impacts continue to be assessed on a project-by-project basis (Fig. 11), limiting these approaches largely to the pilot scale.

Figure 11. Green roof and wall experts excursion on a school building in France.

Source: EFB.

6. Technical elements supporting biodiversity

6.1 Biodiversity enhancement

Green roofs and green walls can significantly enhance urban biodiversity by introducing diverse habitats into the built environment. Their ecological performance depends not only on vegetation presence but also on structure and component richness, including varied substrate depths, heterogeneous planting, and the integration of multiple habitat elements. Biodiversity-oriented design patterns, such as microtopography, patch mosaics and vertical stratification, create niches for different species and support ecological processes.

The fauna supported by green roofs varies significantly between extensive and intensive systems due to differences in substrate depth and vegetation complexity. Extensive green roofs can create habitat for invertebrates adapted to dry, open habitats (e.g. pollinators, beetles and spiders), and may provide foraging or resting opportunities for birds. In contrast, intensive green roofs, with deeper substrate and more structurally complex vegetation, can support a broader range of fauna, including diverse insect communities, birds and, in some cases, small vertebrates, reflecting their closer resemblance to ground-level gardens. The use of exotic vegetation with limited biodiversity value should be avoided. Instead, native species should be predominant wherever possible to support local ecosystems. One of the most up-to-date assessment framework for intensive green roofs is England's Biodiversity Net Gain (BNG) metric which builds on earlier guidance developed in Karlsruhe Germany in the early 2000s. According to this metric, an intensive green roof should:

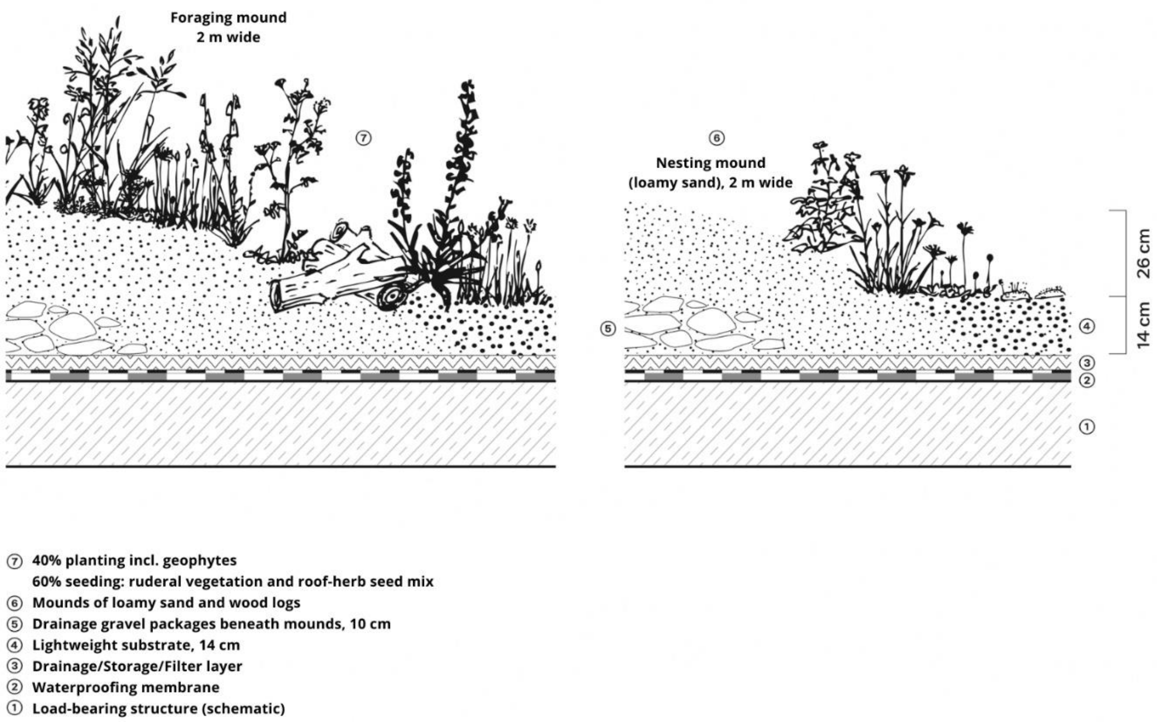
- Comprise at least 70% soil and vegetation, including water features where relevant;
- Include a planting scheme with a minimum of 50% native and 30% non-native of proven wildlife value;
- Limit hard standing and paved surfaces to no more than 30% of total roof area.

Whilst simple extensive green roofs (e.g. sedum-based green roofs) have generic value for biodiversity, the Swiss/English approach provides for greater invertebrate diversity (Fig. 12). In the UK, these are referred as 'biodiverse extensive green roofs' and this approach is based on studies in Switzerland and London in the late 1990s - early 2000s. The design criteria for extensive green roofs depend on local climate conditions but recommend:

- Varied depth of substrate to create topographic variety;
- Seeded and planted with native wildflowers and sedum species which may be of non-native origin. Succulents, such as sedums, can support the dry grassland species through periods of extensive drought. Note that in the UK it is implicit that grass species should not be sown. Grass needs irrigation even in wet maritime climates from as early as April (e.g. London) as such roofs have limited water availability. Whilst technically some species of grass are important food plants for certain species (especially butterflies), this is a compromise between irrigation need and biodiversity.

Additional features should also be created, specifically clay sand mounds and dry log piles, to provide nesting habitat and shelter for invertebrate fauna (especially solitary bees and wasps). The above approach replicates habitat characteristics of links to open-mosaic habitat (UK Habitat) and allluvial river gravel habitat (EU Habitat). Whilst there are other approaches that do benefit biodiversity, such as Wildflower turf roofs, these will require irrigation to sustain grass species during warm periods. Therefore, a balance needs to be considered between irrigation use and the delivery of biodiversity.

Figure 12. Green roof transection of typical biodiversity projects in Switzerland: Schulhaus Looren.



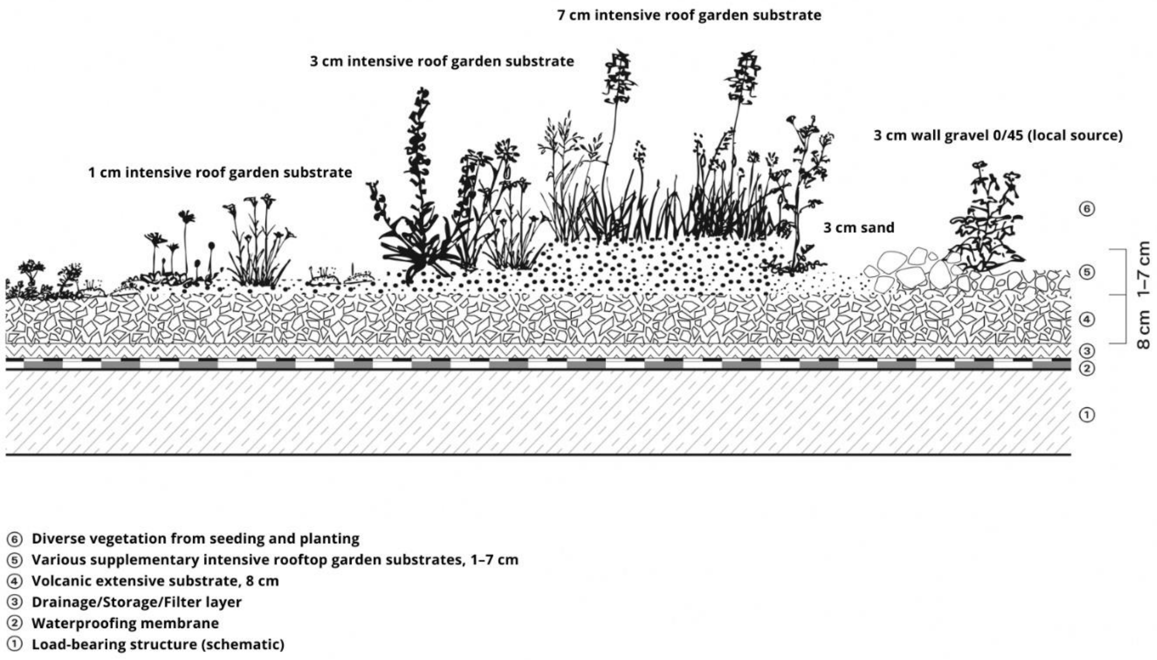
Source: © Jonas Frei, in Brenneisen et al., 2025; translation EFB.

The use of modular habitat and pollinator units, including nesting substrates, insect hotels and flowering modules, further strengthens their role as functional habitats and stepping stones within urban ecological networks (Fig 13).

Furthermore, the biodiversity of green roofs can be implemented by design in terms of plant species selection, substrate used, and shade (Coulibaly et al., 2023). The so-called ‘biodiverse green roofs’ were developed in Switzerland and the United Kingdom to create habitats with biodiversity conservation potential, able to host rare plants and account for animals’ life cycles (Baumann, 2006; Brenneisen, 2006; Grant, 2006; Dunnett, 2015).

The genesis of biodiverse green roofs started when long-term monitoring studies demonstrated that green roofs could constitute refugia for species within cities, and that the species establishment and succession was affected by the substrate type and thickness, climatic conditions and, of course, time. For example, the traditional roofs constructed in Germany at the beginning of the 19th century, characterised by a coat of sand and gravel protecting the waterproof membrane, were first colonised by commensal species occupying empty niches (e.g. ruderal species). In the following 10 to 30 years, they were colonised by meadow species in deeper substrate or shaded areas, or mosses and Crassulaceae in shallow substrate and fully exposed areas (Thuring and Grant, 2016). It is worth mentioning that ruderal species are gaining a relevant role in restoration of degraded lands because of their provision and regulating services, namely erosion control, pollination, and soil quality improvement (Ranđelović et al., 2024).

Figure 13. Green roof transection of typical biodiversity projects in Switzerland: Jakob Burckhardt Haus.



Source: © Jonas Frei, in Brenneisen et al. 2025; translation EFB.

Key design features that differentiate biodiverse green roofs from conventional green roofs can be articulated in three main aspects (Catalano, 2024):

- **Create a diverse roof habitat with different features:** spatial heterogeneity through variation in substrate depth and composition (Fig. 13), coupled with the integration of structural microhabitats — such as ephemeral water depression, deadwood elements, stones, and other refugia — increases niche diversity and supports a broader range of taxa;
- **Use local plant material and species:** the selection of autochthonous species belonging to the same ecotype or biogeographical region, enhances the propagule pressure from local species, facilitating their dispersal across the urban matrix;
- **Do not disturb**: low-intensity maintenance regimes and minimal anthropogenic disturbance enable natural successional dynamics and promote the establishment of self-sustaining ecological communities over time (Fig. 14).

Figure 14. Green roof at the Jacob Burckhardt House, Basel.

Source: © Stephan Brenneisen.

Green walls contribute to biodiversity enhancement in urban environments by introducing vertical habitats that increase vegetation cover and ecological complexity in areas where ground-level space is limited. Through diverse planting palettes, structural layering and microclimatic variation, green walls provide foraging, nesting and refuge opportunities for insects, birds and other urban-dwelling species. Flowering plants support pollinators, while foliage and substrates create shelter for invertebrates, contributing to urban food webs. When designed with native species, varied textures and integrated habitat features, green walls can function as ecological stepping stones, improving connectivity between fragmented green spaces and strengthening urban biodiversity networks.

While living walls offer great potential for biodiversity, some system designs limit the range of plant species because they rely on highly controlled, ornamental planting schemes. However, systems with integrated horizontal substrate layers can accommodate local seed mixes and support more natural vegetation patterns. The introduced Case study of MA 48 in Vienna (Annex 2) represents a system suitable for seeding. These approaches enable the creation of vertical habitats resembling wild meadows, but they require a shift in expectations, moving away from purely decorative aesthetics toward ecologically functional designs. Engaging stakeholders and educating clients about the benefits of biodiverse living walls will be essential to mainstream these solutions.

City administrations can play a key role in integrating Animal Aided Design (AAD) into green façades by providing species-specific nesting aids and guidance for building owners. This approach can be harmonized with historic and existing building stock, ensuring architectural integrity while enhancing biodiversity. A leading example is Vienna's "Gebäudebrüter" program (Species and habitat protection on buildings Vienna), which monitors nesting sites over the cadastre and supports owners and tenants in installing architecture-integrated nesting modules for target species such as swifts and bats, also during façade renovations. By coupling façade greening with nesting opportunities, cities can create multifunctional habitats that strengthen ecological networks and contribute to urban biodiversity goals.

Overall, when strategically designed, these greening systems move beyond aesthetic greening to actively contribute to species support, connectivity and urban ecosystem restoration.

6.2 Habitat template approach

The habitat template approach (HTA) for green roofs and walls was introduced by Lundholm (2006) and consists of identifying habitat analogues (Lundholm and Richardson, 2010) that can be imitated in these novel urban ecosystems. The underlying hypothesis of the HTA is that similarities in environmental conditions — both climatic and edaphic[2] — between natural habitats and man-made systems can guide successful design and species selection. This approach aims to create near-natural patterns with uneven distribution of plant communities and substrate properties. It promotes the use of stress-tolerant species typical of habitats exposed to environmental constraints comparable to those of urban ecosystems, such as summer drought or periodic flooding. The HTA has been tested on semi-extensive green roofs in Japan, where high establishment rates were observed for species characteristic of rocky coastal habitats used as reference models (Nagase and Tashiro-Ishii, 2018). It is crucial to replicate also the abiotic conditions in order to increase the success of target species establishment (Lundholm and Walker, 2018).

In southern France, van Mechelen et al. (2014) applied the HTA to identify plant species that would thrive on green roofs in a Mediterranean climate. Plant selection resulted from the observation of natural landscapes in the region—especially grasslands with shallow soils and limestone surfaces, similar to the harsh, dry conditions found on green roofs, as well as from scientific studies describing typical plant communities of the region. The initial list of suitable plant species was refined by considering key plant characteristics. This study used functional traits[3], including Raunkiær's life forms[4] and Grime's strategies[5]. The final plant selection included mostly hemicryptophytes (perennial herbs that keep their buds at soil level protecting them from heat and drought), along with fewer therophytes (annual plants that survive in dry periods as seeds) and geophytes (perennial plants that survive through underground storage organs like bulbs or tubers). Overall, the study shows how looking at natural ecosystems can help guide plant selection for green roofs in challenging climates.

In Italy, Caneva et al. (2015) proposed a list of plant species based on taxa known to perform well on green roofs and on four habitat analogues: (1) rocks and screes, (2) grey dunes, (3) perennial grasslands, and (4) anthropogenic habitats. Species selection was refined using filters related to

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[2] Edaphic factors refer to the physical, chemical, and biological properties of the substrate, significantly influencing the distribution, growth habits, and diversity of organisms, particularly plants.

[3] Functional traits are morphological, biochemical, physiological, structural, phenological or behavioural characteristics of organisms that influence performance or fitness.

[4] The Raunkiær's system classifies vascular plants into life forms based on the position of renewal buds during periods unfavourable for plant growth.

[5] Grime's CSR theory classifies plants into three primary functional strategies — **C**ompetitors, **S**tress-tolerators, and **R**uderals.

chorology, life forms, and ecological traits (e.g. Ellenberg indicator values) of Italian vascular plants. Notably, this study excluded annual and biennial species (therophytes and short-lived hemicryptophytes), despite their prominence in Mediterranean landscapes — particularly grasslands (Guarino et al., 2020) — and their demonstrated good performance on green roofs (Vannucchi et al., 2018).

Focusing on the Mediterranean context – though the method can be applicable to any region with detailed vegetation data available - Catalano et al. (2013; 2021) proposed what is called a plant sociological or phytosociological approach. This method mimics the natural environment. It uses existing studies of plant communities to identify groups of species that commonly occur together under similar environmental conditions. These groups are organised into categories known as phytosociological classes and alliances. In sum, this approach helps addressing the practical question: 'what to sow or plant together?' By copying natural plant communities, designers can create more stable, resilient, and ecologically coherent green spaces. From a biodiversity conservation perspective, this approach aligns well with the EU Habitat Directive (92/43/CE), identifying habitats that can be replicated on green roofs, including: (1) psammophilous vegetation of Mediterranean coastal dunes (sandy substrates), (2) scree and cliff vegetation (substrates with gravel, pebbles, and sand), and (3) xeric habitats such as garrigues and dry grasslands. A similar methodology has recently been proposed for green wall design (Patti et al., 2025).

In the United Kingdom, Nash et al. (2019) introduced the 'Ecomimicry' approach to green roof design. Ecomimicry is defined as the development of technologies and solutions that meet social needs while respecting the environment by drawing inspiration from local plants, animals, and ecosystems. This approach integrates the habitat heterogeneity hypothesis, which links increased niche and resource diversity to higher biodiversity, with principles of ecological restoration, emphasizing the role of abiotic conditions (e.g., climate, microclimate) and surrounding habitats in shaping species assembly and ecosystem functioning. Consequently, the initial step involves a detailed reading of the local landscape, including soils and substrates, topography, hydrology, aspect, and regionally valuable plant and faunal communities.

In Germany, Schröder and Kiehl (2020) applied restoration ecology techniques to green roofs by testing native seed mixtures alone and in combination with raked material from sandy dry grasslands, which included lichens and mosses. These materials were applied to commercial green roof substrates with low organic matter content, requiring fertilization and irrigation in the initial phase. The seed mixtures comprised graminoids and forbs, including annual species to ensure rapid regeneration and ground cover. Results showed higher establishment rates of grassland species — including red-list taxa — in plots amended with raked material compared to those that were solely sown. This was attributed to microclimatic regulation provided by established cryptogams, which protected vascular plant seedlings, as well as the transfer of fungi and other microbial symbionts contained in the plant material.

Similar techniques are used in Switzerland and promoted by the Zurich University of Applied Sciences (ZHAW), where fresh hay transfer is applied to green roofs whenever possible (Catalano, 2017). Additionally, seeds collected from nearby dry grasslands are used, with donor meadows serving as local propagule sources (see case study in Giubiasco, Switzerland – Annex 2). The application of diaspores via hay transfer offers several advantages: it allows the introduction of large and diverse species pools, often including rare species not available commercially, facilitates the transfer of lichens and mosses through vegetative fragments, and helps maintain genetic diversity within roof populations. Furthermore, the hay layer provides temporary protection for seeds against extreme microclimatic conditions during the establishment phase (although wind must be considered and the hay layer must be anchored to the surface in some way), a function later assumed by cryptogams. Finally, this method represents a cost-effective alternative to commercial seed mixes or manual seed collection.

Biosolar extensive green roofs (Box 5, 6; Fig. 15) can also enhance biodiversity when appropriate solar mounting systems are used. Research and observations show that photovoltaic panels create a mosaic of microhabitats across the roof surface by altering wind and sun exposure. Shaded areas beneath panels, sheltered zones around mounting structures and drier conditions in front of panels support a wider range of plant species and associated fauna. The Noah's Ark Hospice case study integrates a biosolar green roof that became habitat to the Common blue butterfly (*Polyommatus icarus*), a species of conservation interest in the UK.

Box 5. David Attenborough Building - Cambridge, United Kingdom.

Impact: Biosolar extensive green roof (900 m^2) with native drought-tolerant wildflowers, deadwood, nesting features for solitary bees and bird nesting boxes. Estimated 45% retention of annual rainwater runoff.

Challenges: Includes 84.6 m^2 of photovoltaic panels (16 kW) placed close to the green roof.

Success Factors: Likely to produce 16,600 kWh per annum for 30 years. Equivalent to income of £4,374 per annum at current UK prices.

Maintenance: Annual check of drainage and removal of wind-borne invasive species (e.g., *Conyza* spp,). Two persons for half day; estimated cost £200 per annum.

Biodiverse extensive green roof, David Attenborough Building, Cambridge, England (© Green Infrastructure Consultancy)

Box 6. Opernhaus - Zürich, Switzerland.

Impact: 7.700 m^2 extensive, biodiverse green roof (built in line with the Swiss Standard SiA 312), combined with 825 kWp, 2.660 Solarpanels; 740 000 kWh electricity/year. The green roof maintenance is carried out by 4 mowing robots, which can visually recognise the biodiversity areas and drive around them.

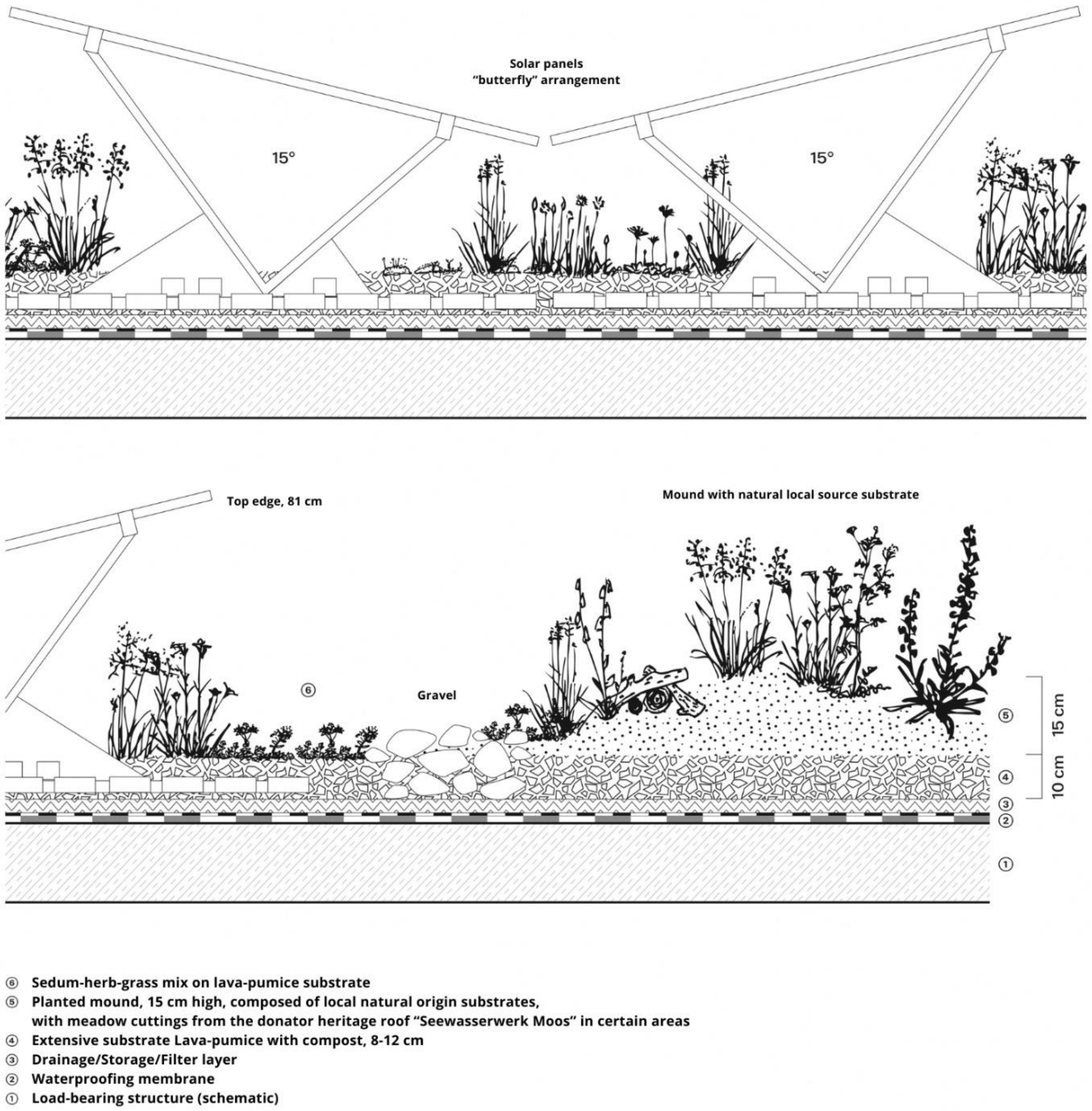
Challenges: Without these innovative robotic mowers, the large roof would have to be weeded out by hand three to four times per year, which would be a financial burden.

Success Factors: Thanks to the innovative approach, it was possible to increase the originally projected output by around 20%. The mowing robot distinguishes between vegetation beneath panels (extensive) and biodiverse features (higher).

Policy Influence: Zürich's mandatory green roof policy and incentive system remain global best practice.

Zürich Opera House (© Stephen Breinessen)

Figure 15. Green roof transection of a typical biodiverse Solar Greenroof Project in Switzerland: Project Requisitenlager Opernhaus Zürich.



Source: © Jonas Frei, in Brenneisen et al., 2025; translation EFB.

More recent technology involves the use of bifacial PV panels on roofs (Fig. 16). Bifacial modules are specifically designed to generate electricity from both sides of the panels but also from indirect solar radiation, namely the reflected light reaching the rear side (Rousset-Rouvière et al., 2025). When integrated with a green roof, these modules can achieve higher energy yields, as vegetation enhances albedo and improves panel performance through cooling effects (Baumann et al., 2019). PV can have a 17% higher yield due to the higher albedo provided, for example, by silver-leaved plants or light-coloured substrates, when compared with standard green roofs (Rousset-Rouvière et al., 2025).

Figure 16. Vertical bifacial PV system on green roof.

Source: © Andreas Dreisiebner, ZHAW (Rousset-Rouvière et al., 2025).

Although not a technical element, greater vegetation structure and species diversity provides more microhabitats, an increased range of larval food plants for invertebrates and more opportunities for pollinating insects. This in turn attracts more wildlife including insectivorous birds and bats. A common limitation with extensive green roofs is the low diversity of vegetation species, typically dominated by Sedum, and this diversity can be increased by including a wide range of drought-tolerant native wildflowers.

Features that have been used to provide microhabitats for wildlife on green roofs include sand piles (for burrowing insects, including, for example, mining bees and wasps), untreated deadwood with a range of holes with different diameters drilled for solitary bees and wasps, and decaying log piles to provide refugia for invertebrates, particularly in extreme hot or cold weather. Other features that have been placed on green roofs to provide habitat and cover for invertebrates include rope made from natural materials, broken masonry, brick, stone or pebbles. Evidence-based advice on how to attract invertebrates to green roofs is provided by BugLife, the invertebrate conservation charity.

To maximise the potential for increasing biodiversity, it is advisable to have substrate as deep as is practical (given loading constraints) and to vary substrate depth to vary the composition of the sward. Shallow features that hold water provide more variation and drinking and bathing facilities for birds.

Artificial nesting and roosting boxes for birds and bats are sometimes fitted on green roofs. Research should be undertaken on which species are likely to occur before selecting boxes. Boxes should have the correct hole size or aperture for the targeted species, and be fitted in suitable locations, at recommended heights and orientation. For example, bird boxes are not normally installed in harsh sunlight or in very windy locations.

Green walls are often vegetated using non-native ornamental species which may have a limited value for wildlife. Biodiversity can be boosted by including more native species, or species with a documented value for wildlife. Where the orientation is suitable it may be appropriate to include bird nesting or boxes in green walls, as well as nesting habitat for pollinating insects (bug hotels), which would usually be south-facing.

Technology is available to automatically monitor biodiversity on green roofs and green walls and this can usually be connected to the internet via Wi-Fi or the cellular network. Microphones that detect bat calls or bird songs that can be automatically identified and recorded are available. There is also equipment that can photograph and identify pollinating insects using artificial intelligence (AI). There is also growing capability in using cameras and AI to identify wildlife. This is a fast-developing area, so designers and specifiers should explore the current availability of equipment. There is also a growing capability to map habitats remotely using aerial imagery/satellites and this is currently being used in the UK to assess green roofs on whether they are Biodiversity Net Gain Good or Poor (extensive biodiverse roofs), or Biodiversity Net Gain or Other green roof (sedum carpets/ blankets/ wildflower turf). This is also being used to identify retrofit opportunities, to upgrade other green roofs to good, and to identify ballast roofs that could be turned into extensive biodiverse green roofs.

Green roofs are increasingly recognized as multifunctional urban ecosystems that provide biodiversity refuges and key ecosystem services, but their performance depends strongly on design and management choices. The GROOVES study (2017–2019) analyzed 36 roofs in Greater Paris, assessing flora, invertebrates, substrates, and ecological functions such as water retention and cooling. Results show that substrate depth and composition (ideally around 30 cm with 10% clay and 60% sand) significantly influence plant diversity and pollinator abundance, while intensive and semi-intensive roofs outperform extensive systems in biodiversity and hydrological regulation. Microbial analyses revealed that roof soils host higher bacterial and fungal diversity than natural soils, with strong stimulation of mycorrhizal fungi, suggesting resilience under urban stress. The study found that soils on green roofs with higher organic content have a comparably high level of microbial biomass (129.4 µg DNA/g soil), about twice the average level measured with the French national soil monitoring scheme (RMQS) benchmark (59.2 µg DNA/g soil). However, the study warns against standardized Sedum-based designs, advocating for varied typologies, local species, and recycled substrates to optimize ecological benefits and reduce environmental footprints (Barra and Johan, 2022).

A recent study in the Netherlands found that plant diversity, shaped by factors like water availability and substrate depth, is a primary driver of arthropod diversity. In the early stages of a green roof's development, stochastic processes such as colonisation, extinction, and priority effects play a dominant role. These processes are largely influenced by the surrounding landscape and the availability of colonisers. As the ecosystem develops, deterministic factors such as substrate depth, water availability, and species interactions become more influential. These factors create environmental filters that determine which species can survive and thrive. With thicker substrates, diverse vegetation and native plants, nature roofs and roof gardens have a higher potential to provide stable, biodiverse ecosystems that are less impacted by external (stochastic) factors and offer numerous ecological and societal benefits. This makes them a preferred choice for projects aiming to maximise the biodiversity in green roof ecosystems (Drukker et al., 2025).

6.3 Animal Aided Design (AAD) approach: species-centric green roofs and façades

AAD was developed in 2015 through an interdisciplinary collaboration led by Dr. Thomas E. Hauck and Prof. Wolfgang W. Weisser, funded by the German Federal Agency for Nature Conservation (BfN). Introduced as a method to embed species-specific habitat requirements into urban planning and design, AAD repositions animals as stakeholders by integrating their lifecycle needs into buildings, roofs, façades, and landscapes. Key milestones include the 2017 Technical University of Munich (TUM) booklet outlining its conceptual foundation and case studies, and the 2021 BfN Script 595 with toolkits and certification aligned guidelines. Since then, AAD has matured through scientific publications, design competitions, and policy instruments, establishing itself as a validated framework for biodiversity inclusive architecture and urban planning.

AAD is an approach that integrates target species such as birds, bats, and insects at the very beginning of the planning process, treating their lifecycle needs for nesting, foraging, and movement as boundary conditions that shape the composition and placement of substrates on roofs and walls. Green roofs are conceived as intentional habitats rather than decorative features, with depth, plant mixes, and substrates designed to mimic natural conditions for species like wild bees, sparrows, and amphibians, while façades incorporate nesting cavities and roosts for swifts and bats directly into structural elements. By linking these habitats into broader ecological networks, AAD creates corridors and stepping stones that support mobile species even in dense urban neighbourhoods, as demonstrated in projects such as the Schumacher Quartier in Berlin. The strategy operates across scales, from individual buildings to entire districts, coordinating measures like pitched green roofs, nesting integrated façades, and planted courtyards to maximize biodiversity. Evidence -based guidelines, including species portraits and technical specifications published in BfN Script 595 and Landscape Research (Hauck et al., 2021), provide detailed requirements for substrates, plant palettes, and connectivity criteria. AAD can align with certification systems and national biodiversity policies, ensuring that green roofs and façades deliver measurable ecological outcomes and contribute to urban resilience.

6.4 Nature-positive design recommendations

A recent publication by Network Nature (Rizzi, 2023) has indicated a set of guiding principles for nature-positive design on roofs and walls (Table 1). The design brief emphasizes biodiversity-positive urban design through NbS to address ecosystem decline and climate challenges. It provides practical recommendations for integrating biodiversity into urban and peri-urban spaces, focusing on mobility networks, building-associated greenery, vacant plots, and brownfields. Rooted in EU strategies like the EU Green Deal and EU Biodiversity Strategy for 2030, the brief advocates for renaturing cities to restore habitats, enhance ecological connectivity, and deliver multifunctional benefits such as climate resilience, water management, and improved human well-being. By promoting green roofs, façades, sustainable drainage systems, and adaptive reuse of vacant land, the document encourages designers, planners, and policymakers to adopt interdisciplinary approaches that reconcile urban development with nature conservation, creating healthier, resilient, and biodiverse cities.

Table 1. Core principles for nature-positive roofs and façades.

Principle	**Application**
Select Target Species	Begin by choosing species (e.g., swifts, bees) and research their needs early
Design Habitat Elements	Incorporate nesting boxes, swift bricks, bat roosts, pollinator modules
Structural Connectivity	Cluster green roofs and façades to enable movement and genetic exchange
Greening Specifications	Define substrate depth, plant mix, wall modularity per species prototyping
Monitor & Adapt	Use project toolkits and portraits
Policy & Certification	Pursue Biodiversity credits (e.g., German Sustainable Building Council - DGNB) and adhere to national biodiversity strategies

Source: Rizzi, 2023.

The design brief (Rizzi, 2023) suggests to:

Choose roof type based on biodiversity goals:

- Extensive roofs: Low maintenance, suitable for windy/exposed sites.
- Semi-intensive roofs: Create flower-rich, prairie-like habitats.
- Intensive roofs: Deep soils allow trees and diverse habitats; highest biodiversity potential.
- Blue roofs: Retain water, enabling temporary wetlands for wildlife.

Plant selection:

- Use native species that provide pollen, nectar, fruit, and seeds for pollinators.
- Avoid monocultures (e.g., only Sedum); mix herbs, grasses, and shrubs.

Structural integration:

- Combine green roofs with solar panels for dual benefits (energy + shading for plants).
- Ensure substrate depth matches structural load capacity (typically 5–30 cm).

Façades:

- Use climbing plants on trellises or tensioned cables for vertical greening.
- Modular green walls can include nesting sites for birds and pollinators.
- Prefer irrigation with rainwater or greywater
- Integrate nest boxes for birds, bats, and solitary bees.
- Avoid artificial lighting on green walls to protect nocturnal species.

Green infrastructure should prioritize native species, structural diversity, and the integration of water-management solutions such as Sustainable Urban Drainage Systems (SuDS) and rainwater harvesting. At the same time, it is important to avoid non-native monocultures and harmful materials, strengthen ecological connectivity across roofs, façades, streets and vacant plots, and engage communities through initiatives like tree-pit adoption and balcony planters.

6.5 Water-sensitive urban design

Urban areas face increasing challenges from extreme rainfall, flooding, and water scarcity, driven by climate change and rapid densification. Traditional drainage systems alone cannot cope with these pressures, making integrated water management essential for resilient cities. Water-Sensitive Urban Design (WSUD) offers a holistic approach that combines stormwater retention, reuse and infiltration, with NbS such as green roofs, green walls, rain gardens, and permeable surfaces. By embedding water-sensitive strategies into urban planning, cities can reduce flood risk, improve water quality, and create multifunctional landscapes that deliver ecological and social benefits. WSUD transforms water from a hazard into a resource, reducing needs for irrigation, and also making green roofs and walls more effective and resilient.

WSUD can be implemented at multiple scales and through different approaches, from city-wide concepts such as ‘sponge city’ strategies to localized measures like rainwater management ordinances and building-level retention systems. Its relevance will grow under the implementation of the Urban Wastewater Treatment Directive and the Climate Risk Framework. Historically, many green roof policies from the 1990s in Germany and Austria originate from rainwater management requirements, including restrictions on discharging rainwater into sewers or taxation schemes that incentivized on-site retention. Nevertheless, the legal framework for connecting rainwater harvesting areas with green spaces or water storage systems is often lacking in cities. Measures are particularly difficult in existing urban areas, where issues such as liability and property rights must be addressed separately in reference to ownership or tenancy law situations.

Rainwater management is a holistic approach that begins at the city scale and extends down to individual building plots. The goal is to interconnect as many permeable surfaces and green spaces as possible, creating a continuous blue-green network that enhances resilience, reduces flood risk, and lowers the cost of implementing green roofs and walls by leveraging shared water resources. In recent years, the sector has actively worked to integrate advanced water management into green roofs and walls, making them more resilient and multifunctional. Innovations include the introduction of flow-control devices such as retention throttles, which regulate the discharge of stored rainwater to prevent sewer overload. Blue-green roof systems now combine vegetation with underlying water storage layers, enabling controlled retention and capillary irrigation. At ground level, planners increasingly connect the root zones of climbing plants to adjacent pedestrian areas, capturing surface runoff and reducing irrigation needs.

Recent developments in Amsterdam illustrate how crate-based water storage systems beneath traditional green roof layers have become a cornerstone of blue-green infrastructure, delivering both substantial stormwater retention and improved biodiversity (Fig. 17). This innovation began with the Polder Roof project in 2013, introducing micro water management through smart valve systems. It was further advanced by pioneers such as De Dakdokters, Metropolder, and later Wavin, and gradually adopted by other suppliers responding to policy requirements set by Amsterdam and Waternet. Through tendering procedures, zoning plans, and ultimately the Rainwater Ordinance, a minimum water storage capacity of 60 mm was mandated for new buildings and major renovations.

Figure 17. Integrated rainwater management at building plot level.

Source: Amsterdam Rainproof, 'Bouw groen en blauw'.

Combined with nature-inclusive building regulations, these measures accelerated the transition toward blue-green roof solutions, making them the new standard for urban development, a guideline on blue-green roofs was developed and provided by Dutch Multifunctional Roof Community (Nationaal Dakenplan) in 2020. The RESILIO project marked a milestone in this evolution, focusing on retrofitting social housing that represents over 40% of Amsterdam's real estate stock, where the challenge of upgrading existing buildings remains significant.

7. Governance and policy

The implementation of green roofs and green walls is shaped by governance frameworks that span multiple policy domains, including urban planning, building regulation, climate adaptation and biodiversity protection. For example, green roof implementation in London was initially driven by species protection legislation. Green roof deployment faces recurring challenges related to regulatory complexity and fragmented responsibilities. Additional issues include risk allocation, liability, and warranty arrangements, which can influence investor confidence and uptake. The deployment of governance frameworks often faces challenges related to regulatory complexity, fragmented responsibilities, supply-chain and local sourcing constraints, financing, maintenance obligations, and coordination across administrative levels. Addressing these challenges increasingly requires multi-stakeholder, public–private partnerships, bringing together local authorities, developers, building owners, designers, researchers and civil society. Such collaborative governance arrangements help align policy objectives with technical expertise and local needs, enabling more effective planning, delivery, and long-term management of green roofs and green walls.

7.1 Policy and regulatory alignment, a reflection of examples

Ideally, specific policies should be created at a city level to ensure that new developments and building refurbishments may include green roofs and/or green walls. Such policies also require detailed supplementary guidance to ensure that implementation meets the policy need. A case in point is the Greater London Authority (GLA) 2008 policy (detailed supplementary guidance) and BNG Legislation in England that has very specific metrics to measure whether a green roof promotes biodiversity.

7.1.1 London: biodiversity driven regulatory framework from the very beginning

In the GLA area, the uptake of green roofs was initially due to protected species legislation (Wildlife and Countryside Act 1981, as amended in 2002). This was delivered at the local municipality level through the planning system. In a few cases, certain roofs were funded by national nature conservation charities, in particular retrofits. However, in 2008 the GLA created a green roof and wall policy with specific supplementary guidance on how green roofs should be designed (GLA, 2008). This guidance is now essentially the BNG metrics for green roofs in England. In 2019 a further report was published to highlight the success of the policy (Grant and Gedge, 2019). This latter report indicated that the total area of green roofs in the GLA area had gone from 200,000 m^2 in 2008 to 1.5 million m^2 in 2017. Whilst there is a lot of interest in delivering BNG in countries across Europe and the world, the only current legislation exists in England; Scotland and Wales are developing their approach at the time of writing. It is too early to measure the impact of this legislation on the uptake of green roofs, especially outside the GLA, but it is likely to be positive.

7.1.2 Insights from the Vienna case – a holistic approach

The City of Vienna demonstrates how a comprehensive framework can successfully embed green roofs and walls into urban development. Infrastructure Adaptation to Climate Change (InKA Project) is a program initiated by the City of Vienna in 2018 to develop strategies and measures for adapting urban infrastructure to the impacts of climate change. Its main goal is to counteract increasing heat periods and the rise of tropical nights in densely built areas, which significantly affect urban living conditions. InKA works through interdisciplinary collaboration between departments of the city and external experts, combining insights from existing strategies and guidelines to create practical foundations for rapid and widespread implementation. Key focus areas include climate-resilient urban planning, green roofs and walls, enhancement of green spaces, sustainable urban design, and water management. By addressing these challenges locally, InKA aims to maintain quality of life in the city during prolonged heatwaves.

The city's nature conservation law (Netzwerk Natur) does not yet explicitly include provisions for green roofs and green walls. However, a set of other instruments, such as technical guidelines (Green Roof, Wall and Solar Guideline) implementation policies (Building guideline *Raumbuch* for public buildings and educational buildings), zoning plans that mandate green and solar integration, and the voluntary indicator GRFWien (Vienna Green Space and Stormwater Management Factor; see chapter 7.1.5), already establish clear requirements for integrating vegetation into new and refurbished buildings as well as public spaces. These are complemented by funding instruments that incentivize the planning and implementation (up to €30k) and by monitoring schemes (Environmental Asset Cadastre) that track technical, ecological and social outcomes, and green space development at large. Together, these measures illustrate how a city can move beyond isolated pilot projects toward a systemic approach, where green buildings are mainstreamed into planning, construction and maintenance.

The applied Implementation example of Raumbuch (building guideline) of the Vienna City Planning and Building Management (MA 34), asks for implementation and/or documentation:

- At the beginning of the planning phase, provisions for nesting opportunities for regionally protected animal species (building-breeding species) must be made in accordance with the Vienna Nature Conservation Act, in consultation with the Environmental Protection Department.
- For both intensive and extensive green roofs, the construction must comply with ÖNORM B 1131.
- For extensive green roofs, a rootable substrate depth of at least 10 cm must be provided; where variable substrate depths are used, the average depth must be 15 cm.
- For intensive green roofs, depending on the planting and level of use, a rootable substrate depth of at least 30 cm must be provided in consultation with the City Gardening Department.
- For extensive green roofs of 300 m^2 or more without solar energy use (i.e. without PV panels or solar thermal systems), different microhabitats must be created in consultation with the Environmental Protection Department.
- At least 10% of the total roof area must be designed with variable substrate depths. The rootable area required in this zone must average 15 cm. Vegetation must consist of a mixture of succulents, grasses and herbs. Varying substrate materials and thicknesses, as well as including structural elements such as branches, stones, sand, rubble piles, and water features, is intended to increase biodiversity (see Green Roof Guideline).

The case overall highlights that effective integration requires a cross-department approach and a multi-layered governance model: regulatory clarity through zoning and guidelines, financial support to overcome initial investment barriers, and monitoring to ensure accountability and continuous improvement. Currently, Vienna is exploring integrating mandatory biodiversity indicators into their policy and funding framework for green roofs and walls. At the same time, the implementation of numerous EU policies (for example on Energy, Water, Biodiversity, Climate Resilience, etc.) puts pressure at cities in Europe and implies changes to existing policies.

7.1.3 The Basel Energy Saving Fund - how incentives sustained the development of biodiverse green roofs

The uptake — both in terms of knowledge development and actual construction — of biodiverse green roofs in cities such as Basel and London was fostered by a combination of direct financial incentives, regulatory instruments, and legally binding requirements (Brenneisen and Gedge, 2012). These measures collectively stimulated the transformation of conventional grey roofs into ecologically valuable green infrastructures.

In Basel, for instance, the Energy Department (the Basel Energy Saving Fund), launched the city's first major subsidy programme between 1995 and 1997. This initiative set in the context of the EU year of Nature Conservation (1995), allocated around one million CHF to encourage both the retrofitting and the construction of new green roofs, offering a financial contribution of 20 CHF/m^2. Building on the success of this initial programme, a second funding campaign was introduced between 2005 and 2007, this time providing approximately 1.5 million CHF and doubling the subsidy to 40 CHF/m^2 for the greening of existing flat roofs (Brenneisen, 2010). Crucially, in 2002 — between the two subsidy periods — the city implemented a building and construction code requiring that all new and retrofitted flat roofs be greened. These mandatory measures had to comply with biodiversity-oriented design principles, including the use of local substrates, a minimum substrate depth of 10 cm, the selection of native plant species and seed mixes, and the provision of habitat features for invertebrates. This regulatory shift ensured not only the quantity but also the ecological quality of green roofs built in the city. The combined effect of the two subsidy campaigns and the binding building code was remarkable. By 2010, Basel had expanded its green roof surface to nearly 100 hectares, up from just 10 hectares before the first campaign (Brenneisen and Gedge, 2012). This tenfold increase positioned Basel as a leading example of how coordinated policy, financial support, and ecological standards can effectively accelerate the adoption of biodiversity-friendly green roofs in urban environments.

7.1.4 Community-based change drivers in the Netherlands, inspired by the EU Green Deal

In the Netherlands, the national community-based network of the 'National Roof Plan' (Nationaal Dakenplan) was developed after its predecessors 'Green Deal Green Roofs' Phase 1 and Phase 2. The partners of the National Roof Plan have diverse background (government, commercial, research, NGOs, etc.) but have a common focus: stimulate the multifunctional roof landscape in the Netherlands, for example by providing Guidelines for biodiverse green roofs (van Heerewaarden and Zeegers, 2019). They work together on sound policy change, knowledge transfer and technical integration of new roof concepts, lobbying for roof attention and showing the value of a thriving roof landscape as a contribution for a liveable city. The National Roof Plan is based on the Dutch polder-principles of working together and respecting each other's role in society to build the case for roof sensitivity and valuable solutions. The Nature Roof Plan steers innovation and uptake of gap closing technologies and services, for example by targeting the multifunctionality of rooftops in delivering an integral approach using a smart digital scenario tooling to simulate optimal rooftop function distribution in a city/neighbourhood (Interreg MultiRoofs project).

7.1.5 Cross-cutting: common drivers across countries: Biotope Area, Green Area and Urban Greening Factor policy tools

Another policy approach that has been successfully used in various cities in Europe is the Biotope Area Factor (BAF, Berlin), the Green Space Factor (GRF) or Green Area Factor (GAF)/Ratio (various cities around the world), and the Urban Green Factor (UGF, Greater London Authority). These planning tools set required ratios for vegetated and permeable surfaces in new urban developments. Whilst these policies are not specific to green roofs but to green space generally, in dense urban areas green roofs are one of the most important elements to ensure that the planning tool requirements are met. Other cities, especially in England, are looking to develop such planning tools.

Local versions of Biotope Area factors have also been tested in Sweden, where Malmö was the first city that implemented it more than 20 years ago, in the western harbour development. Different cities have used different models with varying complexities, but wider implementation has been halted due to lack of legal support. Green space factors can be implemented in guiding documents and in strategic plans but are not enforceable in relation to building permits. Still, green space factors have been implemented through voluntary agreements and contracts between municipalities and developers.

GRFWien on the other hand represents a forward-thinking planning tool designed to address urban challenges of climate adaptation, biodiversity loss, and water management. By combining two key indicators, the Green Space Factor and the Rainwater Management Factor, it enables a quantitative assessment of a site's ecological performance in terms of vegetation coverage, permeability and stormwater retention. This integrated approach supports early-stage planning decisions, ensuring that green and blue infrastructure elements, such as green roofs and green façades, are systematically included to mitigate heat island effects, enhance biodiversity, and reduce runoff. The method builds on international best practices like Berlin's Biotope Area Factor but innovates by linking vegetation depth, substrate type, and water sensitivity into a single dashboard for design evaluation. Ultimately, GRFWien provides architects and planners with a practical, standardized framework to steer urban development toward nature-positive, climate-resilient solutions, making green roofs and façades not optional add-ons but core components of sustainable city design. The GRFWien has not yet been implemented into a regulation, but it is used voluntarily in the context of urban planning competitions or Property developer competitions (City of Vienna, 2024).

In Amsterdam (The Netherlands) the Rainwater Ordinance was a driving policy tool for blue-green roof systems. It was a culmination of former instruments: tenders for challenging the market, subsidizing for added ambitions, community building through the Amsterdam Rainproof program, and zoning plans for a more general approach. Combined with the nature-inclusive building regulation, blue-green roofs were a logical response from the perspective of a real estate developer.

7.2 Identified bottlenecks in the insurance sector

Although none of the analysed case studies reported issues with warranties or liabilities on project scale (other than standard procedures), a recent study by Kroes et al. (2025) indicated the current state of the insurance sector and voiced concerns, as well as opportunities, for further uptake.

From the insurance sector's point of view, several governance and policy hurdles still make it difficult to support and scale up green roof adoption. One of the main challenges is building a solid business case, according to research by the Piloting Innovative Insurance Solutions for Adaptation (PIISA) project (Kroes et al., 2025). Insurers point out that before green roofs can be treated as a marketable product, there needs to be clear proof that a single installation reduces risk, and a quantifiable understanding of the extent of that reduction. Although recent research shows measurable benefits at the neighbourhood scale (Ooms et al., 2025), insurers generally operate across broader and more fragmented geographical areas. This makes it hard to link any loss reduction to individual green roofs, and the possibility of free-rider behaviour (i.e., where some insurers benefit from reduced risk without contributing to uptake) further weakens the incentive.

Working across sectors presents another obstacle. The insurance industry recognises that cooperation with public bodies and the construction sector is essential to encourage wider adoption, but collaboration remains difficult in practice (Kroes et al., 2025). Sectors operate in different ways, and this fragmentation complicates the trust that is needed to scale implementation. Questions around liability during installation and responsibilities for (climate-related) damage once a green roof is in place remain unclear, which adds to insurers' hesitations.

In addition, existing regulations in some European countries limit what insurers can do to stimulate green roof uptake. A key example is the indemnity principle, which prevents policyholders from receiving compensation that would leave them better off than before the loss. Insurers note that this effectively stops them from helping households without green roofs to build back better through climate-adaptive retrofits, as that would count as enrichment (Linnerooth-Bayer et al., 2018; Kroes et al., 2025). These kinds of legal constraints point to the need for policy frameworks that allow insurance mechanisms to better support climate adaptation goals.

On the other hand, European industries and system providers are continuously responding to stakeholders' needs for better integration. A recent project in Austria focussed on delivering a classification for hail resistance of green roofs, allowing insurers to adapt their insurance packages accordingly. The hail resistance of green roof structures and the underlying roof waterproofing have shown that green roofs with a substrate layer thickness ≥ 8 cm have a high resistance. In compliance with the minimum requirements of ÖNORM B3691 and B1131 (ASI, 2019; 2026a), the roof waterproofing does not suffer any damage. Thus, the green roof structure is an effective and sustainable protective layer to prevent hail damage to the roof waterproofing and thus prevent water ingress into the interior of the building, which can lead to reduced insurance costs. Green roofs have been listed in the Austrian Hail register and a specific guidance for Planners and Architects is available (GRÜNSTATTGRAU project).

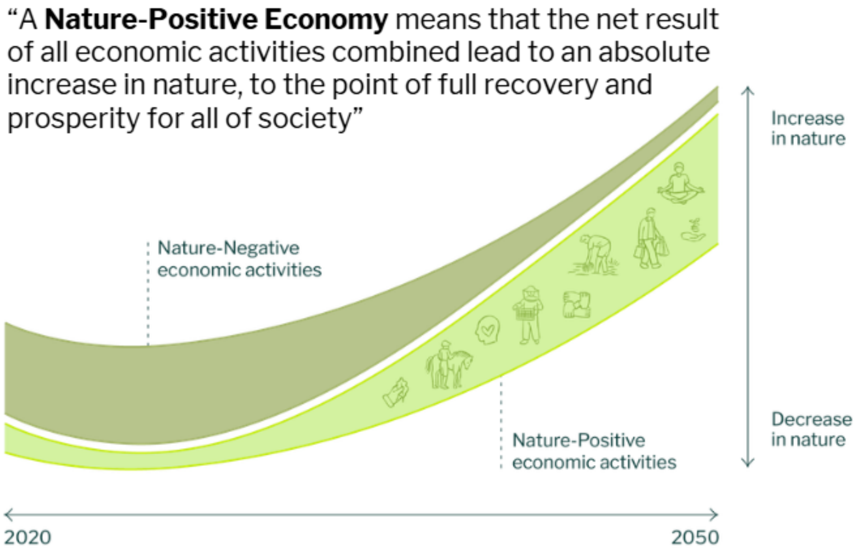
7.3 Supply-Chain and Local Sourcing Constraints

The integration of green roofs and walls into urban policy is shaped not only by design and performance considerations, but also by the realities of supply chains and local sourcing. Experiences across Europe show that local seed mixes and plant material often face challenges of availability, certification and seasonal variability, as well as absent business cases. While native species are essential for biodiversity and ecological resilience, procurement processes can be slowed by limited nurseries, fragmented distribution networks, and the need for phytosanitary compliance.

At the same time, the use of recycled materials and locally sourced components is central to aligning green buildings with the EU Circular Economy Action Plan. While in some countries recycled brick and cork components are part of the green roofing industry, new research pilot projects demonstrate how demolition waste, recycled aggregates and local substrate materials can be successfully integrated into NbS on site, reducing embodied carbon and strengthening local value chains. Yet, legal implications remain significant: material standards, liability frameworks, and building codes, often lag behind innovation, creating uncertainty for planners and installers.

Despite these constraints, the sector shows strong potential. Cities and research facilities are piloting recycling protocols, developing guidelines for native seed mixes, and fostering partnerships with local suppliers to close material loops, for example in Switzerland. These efforts illustrate how challenges in sourcing and regulation can be transformed into opportunities for innovation, market growth and ecological benefit. By embedding circular practices into supply chains, green roofs and walls can become not only climate adaptation and resilience solutions, but also drivers of a nature-positive transition (Fig. 18) in the construction industry (GoNaturePositive! Project). Sustainable urban development processes have the potential to drive nature-positive change, not least by integrating NbS, adopting sustainable and recycled materials, and developing energy-efficient buildings to mitigate negative environmental impacts (Kupilas, 2025). According to the latest Roadmapping workshops for the built environment in 2026, coherent approaches related to Environmental Product Declaration and Life Cycle Assessment and Life Cycle Costing (LCA/LCC)-based assessments are urgently needed.

Figure 18. Nature-positive economy diagram.



Source: GoNP!; Concept note: Framing the Nature- Positive Economy; Koh et al., 2025.

7.4 Technical standards and certifications of technology and training

Across Europe, a robust set of national standards and professional guidelines ensures the quality, safety, and performance of green roofs and walls. For example, the FLL Guidelines provide detailed specifications for the planning, construction, and maintenance of green roofs and walls, while Austria has codified requirements in ÖNORM B1131- Green Roofs, and L1136 -Green Walls (ASI, 2021; 2026a). Switzerland applies SIA312 standards (Green Roofs), Portugal includes technical guidelines, France enforces Règles Professionnelles, and Italy and Czech Republic have embedded green roofs into their national standardization systems for buildings/roofs. These documents define substrate composition, drainage, vegetation selection and maintenance protocols, creating a harmonized technical foundation across the sector. In some countries, they also provide the certification framework for layers, products, works and projects.

In addition to national and industry standards, cities and regions increasingly issue their own guidelines to promote and regulate urban greening. Municipal frameworks often link green roof and wall requirements to local climate adaptation strategies, stormwater management plans, or energy efficiency targets. For instance, local guidelines may stipulate minimum substrate depths, local biodiversity criteria, or encourage the integration with renovation passports, and energy production and certification schemes. Together, these multi-level regulations, from standardization to industry associations to city administrations, ensure that green roofs and walls are not only technically reliable but also aligned with broader environmental and urban policy objectives. This standardization strengthens trust among stakeholders, facilitating large-scale implementation.

On a broader scale, the standardization of NbS is progressing. Recent developments in 2026 include a draft standard for *Sustainable and Smart Cities and Communities – Nature-based Solutions (NbS) – Terminology and Classification* (FprEN 18140; ASI, 2026b) and the publication of a CEN Workshop Agreement on *Nature-based Insurance and Investments – Guidance on Performance and Design Criteria* (CWA 18349; CEN, 2026).

A large number of National associations and the European Federation of Green Roof and Living Wall Associations (EFB) play a pivotal role in advancing the sector. Across Europe, national associations provide specialized training programmes for planners, installers, and decision-makers, ensuring that technical standards are met, and that knowledge of innovative solutions is widely disseminated, for example through training and educational programmes available in Austria, France, Germany, Portugal and the UK (Fig. 19).

Figure 19. Green roof experts training, Vienna.

Source: © Vera Enzi.

At the European level, the EFB and its member organizations collect and analyse market data, offering insights into adoption rates, performance, and emerging trends. This evidence base supports policy development and strengthens the industry's credibility. A recent study (Enzi et al., 2022) summarized findings across different EU markets and came to the conclusion that the competitiveness of a national market also relies on the stakeholder landscape present; for example, alliances between research, industry and the public. Beyond technical training and data collection, the EFB is actively engaged in creating pathways for the sector toward a nature-positive transition. By promoting biodiversity-enhancing practices, encouraging circular material use, and aligning industry efforts with EU climate and restoration goals, the federation and its members are shaping a future in which building greening is not only a technical solution, but also a driver of resilience and social inclusion.

7.5 Governance diversity

The case studies documented here reveal different governance models coexisting across European cities. While many examples follow property owner or municipal mandate approaches, community-led initiatives like Vienna's Sargfabrik demonstrate alternatives based on collective ownership and long-term stewardship. These different models serve different contexts - individual property decisions may work where ownership is distributed, while community-governed approaches may better serve contexts with concentrated ownership or rental housing dominance. Policy frameworks benefit from enabling experimentation across governance models rather than assuming one approach fits all situations. Where appropriate, mechanisms for community land trusts, cooperative ownership, and collective stewardship can complement property-owner and municipal frameworks.

8. Maintenance, monitoring and adaptive management

8.1 Technical maintenance, inspection and health checks

In general, green roof maintenance is essential for ensuring long-term ecological performance and structural integrity. All green roofs will need some level of maintenance. This will vary depending on the type and the regional/local climatic condition. Broadly, there are three types of green roofs, and these types are defined by the level of maintenance they require:

- **Intensive green roofs** require regular intensive maintenance (regular weeding/ irrigation/ pruning, and care of trees and shrubs etc.). In general, this maintenance is weekly, if not more frequent.
- **Semi-intensive green roofs** require periodic maintenance, such as periodic weeding, irrigation and plant care. In general, this is less frequent and mostly needed in the summer months. In winter, just weeding and plant maintenance is usually undertaken.

The maintenance of both these systems in terms of vegetation and soil is similar to that of gardens and parks at ground level.

- **Extensive green roofs** require low maintenance which, depending on the location, may entail very occasional irrigation and an annual or biannual visit to weed out unwanted plants, particularly invasive species, and check the drainage excess, like on any flat roof.

However, maintenance can vary depending on the type of extensive green roof system that is being installed:

- **Biodiverse extensive green roofs**. In general, such systems need relatively frequent maintenance in the first few years to establish the ‘early successional habitat’ when considering open-mosaic habitat (UK habitat) and alluvial river gravel habitat (EU habitat). However, once established, the maintenance is very low as the vegetation has developed into ‘late successional habitat’.
- **Extensive Sedum green roofs**. Maintenance requirements, especially irrigation, will depend on the thickness of the substrate/system. For example, northern and western Europe systems with a good depth of substrate will only need irrigation during extreme heat waves. However, in southern and eastern Europe climates, where summer temperatures are higher, irrigation may be required during the summer months. In lightweight, thin-substrate systems, irrigation may need to be applied much more frequently during the summer period.
- **Solar green roofs**. In general, such roofs are extensive, whether Sedum-based or biodiverse. Their maintenance requirements are the same; however, depending on the solar panel mounting systems, maintenance can be required in front of the panels to ensure there is no negative impact of vegetation to the energy production. This can require taller vegetation that grows directly at the base of the solar panels to be weeded out or cut back, either in the summertime or in the autumn.

One element that is becoming more widely used, especially in the Netherlands for example, is blue-green roofs, which have water storage capacity below the green roof substrate. Using such systems can reduce the need for above surface irrigation (less efficient through direct evaporation of the water), as water can capillary up from the water storage elements towards the substratum and roots to support the green roofs during dry periods.

Importantly, for all three types of green roofs, it is an imperative to ensure good drainage, which requires drainage outlets and channels to be inspected at least biannually. Moreover, the deeper the substrate, the more maintenance is required, as a deeper substrate also opens up to spontaneous colonisation by unwanted weed species. This is particularly relevant for extensive green roofs: over a certain height, depending on the climate, deeper substrates can lead to establishment of woody-stemmed plants. As extensive green roofs are often installed without root barriers, yearly maintenance and removal of woody perennials is absolutely required.

For green walls, maintenance involves irrigation and plant replacement when needed. Ongoing maintenance needs to ensure that irrigation systems function as required, include an inspection of anchoring structures, as well as pruning and maintaining the plants within the wall/façade. Irrigation requirements depend on system type, plant selection, climatic conditions, and rainwater supply options.

- **Ground-based climbers** require occasional guidance, pruning, or support to ensure full surface coverage. Self-clinging climbers can damage the building surfaces by penetrating cracks or voids with their roots or tendrils, potentially compromising the façade integrity if not properly selected and managed. When plant replacement is required, these systems may face challenges in maintaining vegetation continuity. Modular trellises offer several advantages over continuous guide systems, particularly in terms of installation and maintenance. Planting at multiple heights helps limit uneven or dispersed growth along the surface, and facilitates the replacement of unsuccessful plants, ensuring more consistent vegetation coverage over time. In any case, the connectivity to rainwater harvesting (e.g. from pedestrian areas) in the root zone area has priority.

- **Ground-based supported climbers** instead create ventilated air gaps between the building envelope and the vegetation layer. The dedicated support structures prevent vegetation from falling and enable the vegetation along the surface. Also, these systems increase the resistance to environmental loads such as wind, rain and snow. Occasional pruning and guidance may be necessary. Connectivity to rainwater harvesting is an advantage.

- **Planter-based vertical green** can include planters of different sizes mounted in the façade or paced next to it. The plants used range from shrubs to climbers, bushes and trees. The planters mainly carry a layered built-up, similar to green roof built-ups (vegetation substrate, filter, drainage/storage layer). This type of green wall often includes an irrigation system enabling excess water to drain and irrigate lower planters.

- **Living walls** require integrated irrigation to ensure adequate plant development, including water enriched with nutrients or fertilizers. The irrigation is typically supplied at the top of the structure, allowing uniform water and nutrient distribution through permeable layers.

All guidelines published in various countries in Europe provide details of maintenance requirements, timings and tasks. Technical standards by national standardization institutes also provide maintenance protocols, contractual agreements, etc.

8.2 Adaptive management based on ecological feedback

The project atlas ‘Green Roofs. History, Planning, Design’ (Brenneisen et al., 2025) describes and documents 16 flat roofs from across Switzerland. These examples show how sustainable habitats can be planned, designed and managed high above the streets. Brenneisen et al. (2025) have been monitoring, adapting and guiding these projects, in some cases for over 20 years. The projects include also extensive green roofs that received a biodiversity makeover and some of them go beyond standards involving local materials and do-it-yourself (DIY) practices.

The main outcome of Brenneisen’s research on maintenance is that biodiverse green roofs function as long-term ecological systems evolving naturally through succession, much like other habitats. This insight shifts the traditional perspective from intensive, prescriptive maintenance, towards an approach inspired by nature. Instead of constant intervention, the recommended principle is ‘observe and assist only when necessary’, a minimalistic involvement strategy that supports natural processes while ensuring that roofs remain safe and functional. By learning from ecological dynamics rather than imposing rigid control, green roof management becomes a collaborative process with nature, fostering resilience, biodiversity, and reduced maintenance costs over time.

The approach of adaptive management based on ecological feedback requires plant, habitat, social and technical system knowledge:

- to recognize when a roof habitat suffers from invasive species and what strategy is appropriate;
- to recognize which developments are natural and can be left alone (e.g. more moss and grass in rainy years, more herbs and succulents in dry years), or which developments may be dangerous and need action (e.g. an intensive grass roof falling dry in the middle of summer, with an associated fire risk).

Meanwhile:

- adaptive maintenance needs resources, focus and long-term planning;
- biodiverse roofs can become a high-value nature protection measure and can also become a seed-bank for a whole city;
- adaptive maintenance is also fun, full of unexpected new stories and people and sometimes a botanical or zoological ‘unicorn’ appears on stage, which can become a matter of public interest.

As demonstrated by Vienna’s Sargfabrik (Box 7), where locally organized residents have sustained and evolved a multifunctional rooftop habitat for decades building place-based knowledge and calling in experts when needed, green roofs work best when they are designed for people, as well as nature. Wherever feasible, every green roof should incorporate accessibility and safety features appropriate to its neighbourhood so that residents can use, care for, and take ownership of the space. This social connection not only increases the roof’s value for the community but also strengthens onsite maintenance capacity and long-term stewardship.

Box 7. Sargfabrik green roof - Vienna, Austria.

Impact: Social cohesion, biodiversity monitoring, Part of a study that found 91 bee species on 9 roofs in Vienna. (Gruchmann-Bernau, 2019, Kratschmer, 2018)

Challenges: Early governance hurdles for citizen-led projects, unclear frameworks in the 1990s.

Success Factors: Community-driven maintenance, multifunctional design (food, leisure, biodiversity education).

Policy Influence: Informed Vienna's green roof guidelines and promoted cooperative housing models.

Sargfabrik Green Roof (© Vera Enzi)

8.3 Biodiversity monitoring protocols

Biodiversity monitoring on green roofs and green walls typically follows simple, repeatable protocols designed to track species presence, abundance, and ecological performance over time. Standard methods for biodiversity monitoring include vegetation surveys, where plant species cover and composition are recorded using quadrats or fixed observation points. Invertebrate sampling can be carried out through pitfall traps, sticky traps or timed visual searches to assess pollinators and other arthropods. Bird and bat observations can use point counts or acoustic monitoring to monitor the fauna. Green roofs monitoring involves tracking and identifying plant communities and spontaneous vegetation, pollinators and arthropods. Green walls monitoring focuses on species survival, vertical stratification, and habitat use across different wall zones. Many protocols integrate photographic records, georeferenced observations, and citizen-science tools to standardize data collection and enable long-term comparison.

Regular monitoring is crucial to assess green roofs' capability to enhance biodiversity. Typically, biodiversity monitoring campaigns target both vegetation and soil dwellers able to create stable communities, but also other mobile organisms visiting green roofs during their life cycle, such as pollinators and birds. An important aspect of biodiversity enhancement is the spontaneous colonisation, which shall not be arrested except for invasive plants, species which could damage the functionality of the roof, such as plants with particularly strong roots, and species inadequate to the green roof type, such as juvenile trees on semi-intensive green roofs.

From an ecological perspective, green roofs can be seen as islands embedded in the urban matrix (Blank et al., 2017), but if designed by considering the surrounding landscape, they can act as stepping stone habitats for a range of species, especially those with good aerial connectivity.

Moreover, connectivity and species richness have a positive effect on arthropod diversity regardless of the roof height, depth and roof area (Braaker et al., 2017).

Measuring dissimilarities among different roofs in the same area (beta-diversity) is a good indicator of how roofs are connected to each other, multiplying their service as hosts of meta-populations. However, even if not intentionally designed for that, studies suggested that arthropod communities of high mobile species are shaped by habitat connectivity, while low mobility arthropods were more influenced by environmental conditions (Braaker et al., 2014). This suggests that roofs are connected to each other (for highly mobile species), but also to surrounding ground habitats (for less mobile species). For their study, Braaker et al. (2017) used edge density, mean proximity, and mean nearest neighbour distance for each of the habitat-matrix landscapes of the study area, defined on the base of dominant vegetation types (e.g. ruderal vegetation) and at different radius around the study site (e.g. 100, 200, 300 and 400m)

Considering that the roof population dynamics are characterised by colonisation and local extinction, the size (which relates to the chance to catch wind dispersed species, but also to the provision of enough space to host viable and resilient populations), and the distance (the height and the proximity) to richer compatible habitats (species source) are relevant. Thus, variables to consider are the horizontal distance from the closest green patches (in urban context), the distance from a green suburb or city edge, the vertical height of the building, and the number of green areas within a certain radius. Regarding heights, roofs over 20 m are mostly disconnected from ecological networks (Louis-Lucas et al., 2022). Ecological network analysis is used to understand how well different habitats are connected across a landscape, helping to define how easily animals can move between green areas. For this, fine resolution land-use maps allow determining land use (e.g. buildings, roads, parks, and different types of natural ecosystems). Also, target species mobility is studied by setting different radius distance (e.g. 200 m for species with low mobility, 500 m for species with medium-mobility, 1000 m for highly mobile species). By adjusting these distances, ecological network analysis can better reflect the real movement abilities of different species and provide a more accurate picture of habitat connectivity.

To perform ecological network analysis, there are open access software like Graphab5, which uses graph-theoretical approaches to enable least-cost analysis and evaluate the resistance of the landscape matrix by assigning resistance values to land use. Connectivity can be measured at city level or at patch level, where the indicators of the connectedness are: 1) the 'Flux', which is a function of the number of connections among the focal patch and the connected patches, 2) the 'Betweenness Centrality', which highlights strategic positioned patches, and 3) the 'probability of connectivity', namely the probability that two random points are located in interconnected habitats.

Paternity analysis with DNA extraction from about 1 cm^2 of dried leaf tissue proves gene flow within and among roofs, the latter being crucial to overcome the effects of genetic drift (Ksiazek-Mikenas et al., 2019). In this case, a primary role is given to highly mobile pollinators (able to move a long distance), which increases population connectivity, thus limiting inbreeding.

Plant species assemblages can be monitored following the Braun-Blanquet method, which consists of recording all the vascular plant species growing on a certain surface (varying between 1 and 10 m^2) and their cover (in percentage). Other parameters generally recorded during sampling are the mean vegetation height (min and max), when possible, the substrate thickness and exposition (relevant to study the biocenosis of north and south facing pitched roofs, for example), and inclination (in degrees). Mosses and lichens are generally recorded in terms of coverage and rarely determined at species level. In the case of biodiverse green roofs characterised by changing substrate type and thickness, a stratified random sampling is recommended to select representative samples for each habitat patch (Vanstockem et al., 2019). Considering that roofs have clear boundaries compared to grasslands on the ground, it is common to prepare also thorough species list by walking randomly over the roof (roof-level sampling) and detect the species not sampled within plots. It has been shown in this regard that the sampling methods on quadrates detect most of the species, so it can be considered representative of the whole roof (Muratet et al., 2024).

The analysis of vegetation can provide biodiversity measures not only in terms of plant species richness (alpha diversity) and evenness (similarity among plots), but also in terms of functional trait diversity (considering the community weighted mean at roof level), as a proxy of resilience. For example, Grime's CSR strategies and Ellenberg Indicator Values (i.e., temperature, light, continentality, soil reaction, nutrient content, and humidity) can be used as a proxy of local conditions, indicating, for example, higher thickness and humid soil when competitive species are dominant, or shallow, poor and drained soil when stress-tolerant species dominate, or rich in nutrient substrate or disturbed when ruderal species are prominent. In long-term studies, these traits can demonstrate the response of green roof communities to stressors when comparing multiple vegetation surveys over time, especially when plants were initially planted in regular patches and the roof was not irrigated or maintained to keep the initial appearance as it was designed. For example, it is possible to observe shifts from competitive species towards more stress-tolerant species over time (species turnover). Phenology is determined weekly, recording flower development, namely bloom time, number of flowers, fruits or seed capsules.

For surface-dwelling arthropods, sampling can be carried out along transects in repeated sessions in spring and summer (between May and July/September on a weekly basis) with a vacuum catcher for a fixed time (e.g. 10 minutes), or positioning pitfall traps filled with bactericide solutions and protected from rain with transparent lids detached from the ground. Flying arthropods can be captured using a nondirectional trap combined with a yellow pan trap placed 1.5 m above ground (Braaker et al., 2014, Barra and Johan, 2022), or multiple colours (i.e., blue, red and white) pan traps, emptied daily. In all cases, identification is carried out in the lab by specialists; therefore, samples must be stored adequately, e.g., in 70% ethanol (Jacobs et al., 2023). Pollinators can be recorded over a fixed time, for example 2 minutes, by noticing all the morphospecies visiting the roof and floral reproductive structures (Guidi et al., 2024).

Long-term monitoring is rare but crucial to assess the biodiversity and the resilience of the established community to stressors such as heat waves and prolonged drought without irrigation over time, but also changes in soil activity such as pH or C/N ratio (Catalano et al., 2016; Thuring and Dunnet, 2019). Monitoring campaigns should run in late spring for temperate and continental climates (mid-May, early June) and in early spring in Mediterranean climates (end of March, mid-April). Frequency should be once a year to have a constant overview, but this also depends on the budget that can be allocated, considering that the effort is high. Permanent plots are recommended for long-term monitoring, considering that the difference between species sampled with plots and the ones discovered with walking surveys is not high. Random sampling is also adequate when the location of historic and previous sample positions is unknown.

The metrics commonly used to characterise biodiversity are taxonomic diversity and abundance (Coulibaly et al., 2023). Species richness (data from vegetation surveys and total species list at roof-level) is the most used indicator in vegetation monitoring. Shannon diversity index (which also considers the species abundance, namely species percentage cover) is used to compare species diversity among different roofs (Lönnqvist et al., 2021).

Functional diversity (FD), or species trait diversity, is also used as indicator together with species richness; where FD is not necessarily higher in species-richer habitats (Braaker et al., 2017). Plant traits include: seeds longevity, seeds mass, seeds and pollen dispersal strategy, Grime – CSR strategy, Leaf Nitrogen Content, Leaf Specific Area – SLA, Leaf Dry Matter Content - LDMC (Catalano et al., 2016; Vanstockem et al., 2019; Thuring and Dunnett, 2019). FD is measured following the community weighted mean (CMW) to consider the effect of species abundance in the overall performance (mass-ratio effect) while species traits are generally retrieved from open access resources such as the TRY6 and LEDA7 plant trait databases, or measured on site, increasing the effort needed for such analysis due to high sampling effort. If FD is measured as Rao's quadratic entropy (Vanstockem et al., 2019), it combines functional richness and divergence (known also as FD dispersion). Anemochory is the dominant mechanism of dispersal (long distance dispersed species). Plants Functional Dispersion (FDis) (below- and above-ground) together with Phylogenetic Diversity (PD) provide relevant information on the green roof's ecosystem function (benefit linked to high plant biomass), even more accurately than species richness (Hao et al., 2025).

It is possible to involve citizens in monitoring pollinators on green roofs as done for the inventory of invertebrates for the GROOVES project (Green ROOfs Verified Ecosystem Services) carried out by the Regional Agency for Biodiversity in Paris, using SPIPOLL, a citizen science software (and app) developed by the National Museum of Natural History. The protocol consists of taking photos for 20 minutes, collecting interactions between insect pollinators and the selected flower.

Long-term studies have the downside that are carried out by different people, which can cause bias in surveys. Moreover, this kind of monitoring is time-consuming and requires specialists to determine species on site (plants and pollinators) and in labs (insects collected with pan and pit traps).

8.3.1 Citizen science in monitoring

New tools, such as animal and plant identification apps, and training by professionals, can help citizens take on inspection and maintenance tasks if the project environment allows. Site visits can be organized and over time expertise can be built. Citizen science offers a valuable approach for monitoring biodiversity on green roofs and green walls, enabling broader data collection and increasing public engagement with urban nature. Through collaborative research, citizens can contribute directly to identifying and documenting plant and animal species, complementing formal scientific monitoring and helping to fill data gaps (Fig. 20).

In the GRAVITY project, several green roofs and green walls in Lisbon were monitored to assess their biodiversity value through a combination of structured surveys and citizen-science observations. At the Alcântara Wastewater Treatment Plant (ETAR) site, with 27,200 m² of semi-intensive green roofs, the Biodiversity4all platform yielded 207 taxonomic records, including 73 plant, 36 insect and 17 bird species, while the 250 m² living wall at the CCB generated 20 observations across plants, insects and birds. Continuous monitoring at the Calouste Gulbenkian Foundation's gardens and green roofs produced 1,280 observations between 2009 and 2023 using the iNaturalist platform, with birds and insects as the most frequently reported groups. Results showed that combining green roofs and ground-level gardens creates continuous, species-rich habitats, and that structured activities boost taxonomic diversity and improve coverage in less visited areas (Oliveira et al., 2025). Seasonal and temporal trends — such as higher citizen participation in spring, summer and weekends — were also identified, reinforcing the value of integrating community engagement into biodiversity monitoring efforts.

These citizen-generated datasets support researchers and policymakers by providing spatially rich, real-time information on species presence and ecological trends, thereby strengthening the understanding of how green roofs and green walls contribute to urban biodiversity.

Figure 20. Capturing pollinators on a green wall in Budapest.

Source: © Vera Enzi.

8.4 IoT and remote sensing for performance tracking

The integration of IoT technologies and remote sensing is increasingly enhancing the monitoring and performance tracking of green roofs and green walls. Embedded sensors and connected devices enable continuous measurement of key parameters, such as substrate moisture, temperature, humidity, plant health and water use, providing real-time insights into the system functioning. Remote sensing techniques and *in situ* monitoring support evidence-based management, early detection of system failures and long-term evaluation of environmental benefits.

Some green roofs and green walls utilise cloud-based systems of IoT sensors as part of their design (SEL and UoS, 2020; Elkadi and Heysham, 2022), continuously collecting and transmitting environmental data to monitor the system irrigation and overall performance. These can include soil moisture sensors embedded in the substrate to measure water availability for plants at a certain substrate depth, triggering irrigation only when thresholds are met. Similarly, temperature and humidity sensors track microclimate conditions on the surface, helping detect heat stress or drought impacts. Water level and water flow sensors installed in drainage outlets or attenuation tanks can help quantify stormwater retention and discharge, capturing the roof's hydrological performance. All this data is compiled in a cloud control platform that centralises all sensor data, is visualised through dashboards, and enables remote monitoring by estates or management teams through automated alerts and integration with building management systems (BMS).

Manual biodiversity monitoring is generally time consuming and expensive, which means that it is impossible to carry out repeated monitoring several times during a single growing season. Therefore, manually collected biodiversity data is very much dependent on conditions at the sampling time, and it can be hard to create a solid biodiversity baseline that could be used to direct management actions. Consequently, there is a high potential to use smart sensors for biodiversity monitoring on ground- as well as roof-based ecosystems. These systems include, for example, visual sensors that record wing beat frequencies of flying insects (Rydhmer et al., 2022), and audio sensors that are able to distinguish between different bird species or quantify the amount of pollinator activity (Hill, 2017).

Additionally, the rise of eDNA technology in combination with AI-supported remote sensing approaches could revolutionise the biodiversity monitoring of green roofs (Gout, 2025). The urban setting, with access to strong wireless networks as wells as a clear view of the vegetated systems, makes the monitoring of green roofs and green walls a perfect starting point for testing new monitoring systems. The use of automated sensors means that there is a direct potential for action and adaptive management of the green roofs in response to changing green roof biodiversity.

There is also a growing use of remote sensing and AI to baseline and monitor habitats (Petrou, 2015), which has also been used on green roofs in the UK (Green Infrastructure Evaluation Tool for Urban Nature-Based Solutions; GENTIAN, 2025). In fact, there are commercial remote sensing and AI products that in various instances can differentiate the quality of green roofs from a biodiversity perspective, something that has high relevance in relation to BNG metrics, for example. This can be particularly useful to get baseline data and monitor processes and developments at large scales, such as at city level. There are ongoing commercial activities to ground truth the systems and develop integrated approaches that combine the use of bioacoustics information from control sites with the use of remote sensing and AI to qualify the habitat quality of other roofs within a given area.

Another example is the Green Transformation Information Factory (GTIF) Austria, provided by the European Space Agency (ESA, 2025). GTIF's current scope includes five domains: Energy Transition, Mobility Transition, Sustainable Cities, Carbon Accounting and Earth Observation (EO) Adaptation Services. GTIF's Sustainable Cities module includes dedicated tools for green roof implementation, featuring automated detection of existing green roofs, analysis of maximum land surface temperatures, and planning support for rooftop greening measures. It leverages ESA data, satellite data and Geographic Information System (GIS) analytics to identify suitable building surfaces, assess the cooling impact of vegetation, and prioritize sites where green infrastructure can most effectively reduce urban heat and enhance environmental resilience (ESA, 2025). Another ongoing Project called GET-ET aims to develop an EO-based service integrated into the GTIF platform, providing high-resolution evapotranspiration maps for urban green areas and green roofs, as well as renewable energy potential data for Austria, to support policy decisions and private sector planning for climate mitigation and adaptation (GET-ET project).

9. Financial and market conditions

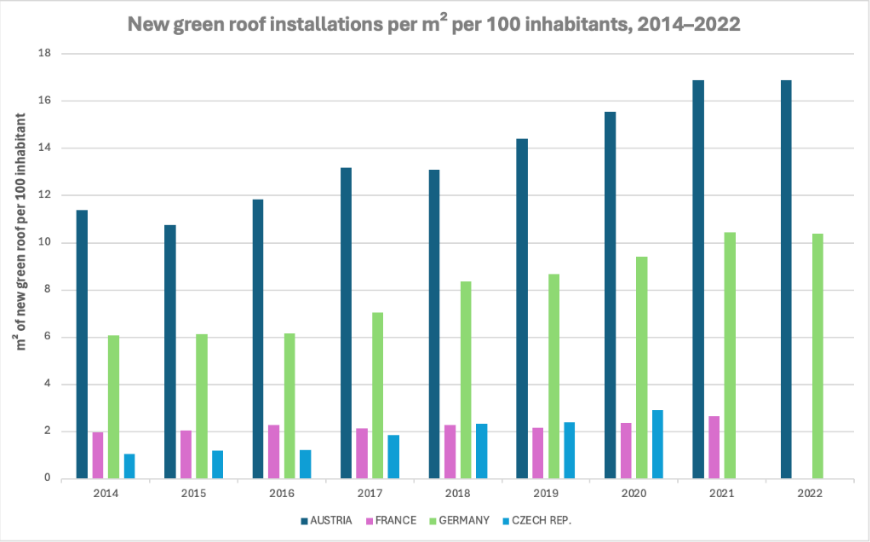
Nature-based enterprises play a central role in delivering NbS by providing products and services where nature is the central, sustainably used resource. They represent the most common organizational type engaged in implementing nature-based solutions and span eleven categories of economic activities, from eco-tourism, smart technologies, community engagement, ecosystem restoration to green infrastructure. Their diverse contributions fill gaps not captured by traditional industry classifications, making them essential actors for scaling NbS and enabling effective policy support and market development (Kooijman and McQuaid, 2021).

According to the green market studies on the green roof and wall sector, a dynamic growth is expected for the next years due to rising awareness for the need of climate change adaption measures and investments in NbS. These will be triggered by proactive strategies of cities which take greening technologies already strongly into account. The successfully implementation of NbS in the future requires know-how and constant training and education to recognize innovations and potentials, and represent the basis for decision-making to environmental issues. Regulations and funding schemes are evolving quickly from these strategies and will push the innovation within the greening sector forward (Enzi, 2022).

The green roof and wall market in Austria, along with its value chain of planners, R&D teams, system providers, component manufacturers, contractors, and maintenance experts, is experiencing continuous growth between 10-17% annually (Formanek, 2024).

Recent studies from national markets in Germany, Czech Republic, France, the UK and Spain confirm this trend (Green Market Report Project), while the supply per inhabitant allows a differentiated market view (Fig. 21). Local markets are also accelerating, driven by ambitious urban targets such as Vienna’s plan to ensure every resident has access to public green space within 200 meters. Rising cooling demand is another major driver; according to a recent study by the University of Natural Resources and Life Sciences of Vienna (BOKU), the cooling load in residential and office buildings is expected to more than double by 2050 (Wimmer, 2025). Passive strategies for shading, including building-integrated green roofs and walls, will therefore become essential for climate adaptation and energy efficiency.

Figure 21. Newly deployed green roofs in m^2 per 100 inhabitants in selected countries, 2014-2022.



Source: EFB, 2025.

Green roofs and walls today are implemented on a wide range of building types, from public infrastructure and residential complexes to industrial facilities and healthcare institutions. While new developments increasingly integrate these systems, the focus of innovation lies in technologies that enable retrofitting and renovation. Advanced solutions such as lightweight substrates, modular systems, and sensor-based irrigation make it possible to green older structures without compromising structural integrity or energy performance. These retrofit technologies are key to scaling urban greening, as the majority of Europe's building stock consists of existing structures rather than new builds. By prioritizing renovation-friendly designs, cities can unlock vast potential for climate adaptation, biodiversity enhancement, and improved urban resilience.

Even in mature markets, the potential for scaling remains; for example, currently about one in ten flat roofs in Austria is built as a green roof, while other markets report comparable numbers. This highlights a significant opportunity across the building industry.

Especially small to medium cities have missing frameworks and capacities, while most capital cities in Europe have dedicated green roof and wall implementation plans. Some (as in Germany) even compete annually in supplied green roof m^2 per citizen (BuGG, 2023).

However, a persistent challenge is that the parties financing these projects are often not the ones who directly benefit from the ecosystem services provided, as is common with many NbS. True value emerges through shared experience and ownership, yet this disconnection can lead to compromises and low-quality implementations, which rarely support biodiversity effectively. To overcome this, alternative cost-sharing models, engagement in operational expenses, and innovative approaches such as Social Return on Investment (SROI), green bonds and impact-based financing are currently being explored. These mechanisms can align incentives, improve project quality, and ensure that ecological and social benefits are fully realized.

The cost of installing a retrofit green roof on an existing building include design and planning, material acquisition, such as substrate, waterproofing membranes, modular panels and other, as well as cost of labour, lifting equipment and specialist contractors for the installation. Other costs that emerge post-construction can be seasonal maintenance, irrigation checks, replacement plants and, in case of installed cloud-based systems, the monitoring of sensors, platforms and supplementary infrastructure such as strong Wi-Fi. The costs in such retrofit cases are considered front-loaded, with long-term savings and ecological co-benefits to follow across the building lifecycle. Savings can be achieved through hiring local labour and consultants, use of local materials and equipment, and use of native plant species from local nurseries. However, additional costs may arise from fragmented supply chains (depending on city and country), and limited awareness of owners and developers on local biodiversity-oriented alternatives.

9.1 How much does nature on roofs and walls cost?

Biodiversity features such as nesting aids, sand lenses, substrate hills, deadwood, and microhabitat elements are critical for creating heterogeneous habitats on green roofs and walls. These features provide nesting sites for solitary bees, shelter for insects and structural diversity that supports pollinators, birds, and other urban wildlife. Despite their ecological importance, these features are often overlooked in standard design processes and planning software, which tend to prioritize uniform vegetation layers and technical performance metrics. Because these elements do not generate financial margins for construction companies and are perceived as 'extras', they frequently disappear during value engineering or late-stage project adjustments. This is a missed opportunity: their cost is minimal compared to overall project budgets, yet they deliver disproportionate benefits for biodiversity, resilience and ecosystem services. Integrating these features systematically into design standards and planning tools is essential to ensure they are not lost before implementation.

The case studies published by Brenneisen et al. (2025) have shown that even long time after the initial installation, biodiversity features can be integrated on simple extensive green roofs, respecting their structural stability. Additionally, the city's green management/nature protection department could support the effort by providing locally sourced materials, creating a win-win for ecological resilience and multistakeholder engagement. The city of Vienna's nature protection unit is a living example, as it provides different nesting modules for projects. Another promising approach lies in local neighbourhoods. The 'Asphaltknackerinnen' initiative in Basel is a powerful example of how cities can mobilize community-driven action for biodiversity, transforming sealed surfaces into green habitats through hands-on engagement and social inclusion. Such teams could ensure, that low-cost but highly valuable elements, such as nesting aids, sand lenses, substrate variations, and deadwood, are not omitted during implementation (Box 8). Such an initiative could also foster social entrepreneurship by engaging vulnerable groups in the delivery and maintenance of these features.

Box 8. Klinikum 2 Green Roof - Basel, Switzerland.

Impact: Biodiversity hotspot (orchids, butterflies, black redstart), patient well-being, and stormwater compliance.

Challenges: None major — Basel's strong regulatory framework ensured success.

Success Factors: Local materials, ecological design, and long-term monitoring.

Policy Influence: Basel's mandatory green roof policy and incentive system remain global best practice.

Klinikum 2 Green Roof (© Stephan Brenneisen)

9.2 Biodiversity Credits and other financial incentive systems

Eco-points, Nature Credits and other biodiversity offsetting systems for green roofs and walls present both opportunities and challenges. On the positive side, such frameworks can create clear incentives for developers to integrate ecological features, like nesting aids, diverse substrates and microhabitats, by assigning measurable biodiversity credits. This approach can help mainstream nature-positive design and ensure that projects contribute to urban ecological networks. However, there are also drawbacks: offsetting systems risk becoming a 'tick-box' exercise if they prioritize compliance over quality, leading to minimal or tokenistic interventions. Additionally, the complexity of verification and the current lack of standardized metrics for rooftop biodiversity limits adoption. These schemes may favour large developers who can absorb administrative burdens, while smaller projects miss out. To maximize benefits, credit and point systems should be simple, transparent, and linked to performance-based outcomes rather than surface-level greening alone. The EU taxonomy classification system already offers a coherent approach for private sector action. EU's Roadmap towards Nature Credits was launched in 2025.

A recent sectoral brief for the built environment highlights the sector's significant environmental footprint, urban sprawl, resource extraction, and high energy use. It outlined the importance of private sector roles through organizations like the World Green Building Council and World Business Council for Sustainable Development and their potential for certification (Kupilas, 2025).

9.3 Public-private partnership (PPP) models

Across Europe, insurers notice that consumer awareness remains a barrier: many homeowners are still not fully informed about the benefits of green roofs, or the financial incentives available to them (Grassi and Carrai, 2025). To address this, insurers are stepping up their communication efforts in the hope that better awareness will stimulate demand and, over time, help lower costs as the market grows. For example, they guide their policyholders to available municipal subsidy schemes for green roofs. Premium discounts on home insurance are sometimes mentioned as another possible incentive, but because home insurance premiums are already relatively low, any discount would have limited influence on a homeowner's decision to install a green roof (Kroes et al., 2025). For this reason, direct financial incentives from insurers remain modest at this stage.

Public–private partnership (PPP) models are viewed positively for their potential to improve data sharing, strengthen knowledge exchange and pool funding, which could help reduce uncertainty around green roof investments (Kroes et al., 2025). Still, earlier concerns about liability need to be resolved before these partnerships can fully support market uptake. At the same time, more insurers are now including green roofs in their standard policy coverage, meaning that damage is compensated when incidents occur. This development is seen as an important step toward creating a market environment that better supports the adoption of green roofs (Kroes et al., 2025). Additionally, some studies show that accessible green roofs can increase property value by approximately 7%, linked to amenity and well-being benefits (GMCA, 2020), which supports this shift in the market.

Taking a different perspective, many Cities in Europe already have vast experience in Public-Private-Partnerships. Grätzloase in Vienna is a public–private partnership (PPP)-inspired initiative that empowers local citizens, supported by the City of Vienna and the NGO Lokale Agenda 21, to transform public car parking spaces into 'parklets' with greenery, seating and play areas, improving urban microclimates, social cohesion and neighborhood life (Grätzloase - LA21.wien project). Participants receive advisory support, networking opportunities and grants of up to €5,000. This exemplifies an NbS-driven PPP: public funding and oversight, civil society or private implementation, and shared risk and benefit to deliver sustainable urban green spaces. In twelve districts of Vienna, 'Grätzllabore' (neighbourhood labs) support engaged citizens in actively shaping their communities. Through a co-creative process, local administration, district politicians and residents work together to implement sustainable projects. The Grätzllabore have already helped deploy green wall projects.

The Vienna example aligns with broader NbS PPP frameworks, where the public sector collaborates long-term with private or nonprofit partners to deploy green infrastructure, leveraging private resources and expertise to deliver public goods like biodiversity, climate resilience, and improved urban environments. Such models combine functions — design, build, finance, maintain — under a single contract, transferring specific risks to private partners while focusing on outcome delivery (Brears, 2022).

9.4 Combining functions to add optimal value for initial financing, a lesson from the Netherlands

The EU funded LIFE@Urban Roofs project, carried out by the city of Rotterdam, came to the conclusion that in terms of simple economic return on investments calculations, green roofs hardly ever become beneficial in a traditional economic sense. This observation is backed up by other expert voices from elsewhere in Europe. Therefore, a societal cost benefit analysis (SCBA tool) was developed to be able to calculate the societal benefits of rooftop functions, focusing on multifunctionality. This Multifunctional rooftops calculation tool allows to reallocate the investments needed to the most suitable stakeholders that benefit the most from the investment.

The Dutch foundation Nationaal DakenPlan (National Rooftop Platform) combined these findings in a facts and values compilation (Facts and Values Multifunctional Roofs) that indicates the various benefits of multifunctional (green) roofs. Explaining the benefits of rooftop functions, especially combinations of rooftop functions, has proven effective in ensuring economic viability for initial investments. The Dutch Nationaal Dakenplan developed in recent years a robust and substantiated knowledge base on multifunctional roofs (Kennisbank).

10. Recommendations and actionable steps

Building on case studies and thematic analysis, this section offers practical recommendations for policymakers, planners, and practitioners. It aims to translate observed practices into actionable guidance across the dimensions explored in the report. They include a short policy navigator for local authorities, pathways for adopting biodiversity-positive technologies, strategies for capacity building and training, and approaches to integrate biodiversity and maintenance requirements into public procurement and contracting processes. The specific analysis of the case studies has provided valuable insights that allow for general, as well as specific recommendations.

10.1 The Nature Restoration Regulation's urban aspect

In densely populated urban areas, such as large cities, building land is increasingly limited and cities struggle with densification to accommodate an increasing number of residents. The NRR's urban greening targets of no-net loss and the increasing trend of green spaces are therefore likely to be a challenge for municipalities. The integration of green infrastructure, namely green roofs and green walls, into the built environment can provide a solution for building owners, planners and politicians to accomplish multiple goals simultaneously. Converting underutilized air space over new infrastructure into green and multifunctional spaces needs to become more commonplace, as it is a smart, triple-win way to deliver the NRR targets. Greening cities supports adaptation to climate change and to the risks it brings to highly vulnerable urban areas. Green spaces, especially when installed on buildings, can indeed mitigate the impact of heavy rainstorms and heat waves, lowering the Heat Island Effect and the building cooling needs, and providing effective NbS to stormwater management. Crucially, green roofs and walls also act as the stepping stones needed in cities to connect green spaces and increase habitat functions. Green roofs in urban environments help maintain and increase biodiversity and play an important role in supporting pollinators, which are essential for the persistence of plants in cities and beyond. Therefore, the installation of these solutions would also support Member States restoring their pollinator populations, in accordance with Article 10 of the NRR, which has similar objectives and timelines as the urban green spaces targets of Article 8.

10.1.1 What needs to be implemented?

In the planning phase, Member States must determine and map their urban ecosystem of cities, towns and suburbs, according to Article 14 (4), to identify the green spaces of these specific areas, which will be the basis to set their urban greening targets. Following this mapping, Member States will have a sense of the scale of the greening needed, or loss of green to be compensated thereof, in the next few years. To ensure the greening of urban areas, Member States must adopt the necessary policies and measures to, first, stop or even revert the loss of urban green spaces by 31 December 2030, and then ensure that the greening of urban spaces takes place until the 'satisfactory level' identified is reached.

These measures can consist of a variety of policies, from binding requirements for cities and towns, complemented by supportive financial and technical frameworks, to the creation of parks and gardens, or the greening of buildings and infrastructures, such as integrating green roofs and walls on existing or new buildings. All these measures should take into consideration the benefits of green spaces for inhabitants' well-being and their overall positive and multiple impacts on urban environments.

10.1.2 How should green roofs and walls be treated across the planning, policy, and monitoring stages?

10.1.2.1 Baseline setting

If city-level data on green spaces and tree canopy cover is not already available, a detailed mapping should be carried out using advanced GIS and remote sensing techniques, including Copernicus satellite imagery (Copernicus), Normalized Difference Vegetation Index (NDVI) analysis (EARTHDATA), and LiDAR technology (NEON). This process should encompass a broad range of NbS and green infrastructure, including green roofs. Digital analysis can be complemented by field surveys to capture local features such as green walls, small parks, inner yards and allotments.

EXAMPLES

— *A practical example is Vienna's 'Umweltgut' cadastre, which also includes assessments of green roof and wall potential and stock and solar integration from a citywide perspective.*

— *For ecological baselining, the Île-de-France GROOVES inventory (*Note Rapide #44, L´Institute Paris Region*) applied repeatable field protocols on vegetation, invertebrates, substrates and services, providing an auditable roof-level biodiversity baseline that complements satellite products.*

— *The GMCA IGNITION Living Lab offers a replicable data framework to baseline urban greening assets and their performance, supporting evidence-based prioritisation.*

— *Amsterdam's roof cadastres and rainwater ordinance demonstrate a policy-linked baseline approach that quantifies rooftop retention potential as an input to city GI mapping.*

— *Helsinki's 'Greenest on the Green' baseline combined microclimate exposure with social equity criteria to identify priority greening at block level.*

10.1.2.2 Planning

Building on the baseline data, the next phase focuses on identifying priority areas and setting strategic greening goals. This begins with mapping zones that lack sufficient green space, have low canopy coverage, or face high exposure to urban heat, air pollution, or flood risk, supported by microclimatic analysis, thermal comfort indicators (PET) and rainwater management data. These steps are highly relevant for upcoming policy cycles under the Climate Resilience and Risk Management Framework. Special attention should be given to socioeconomically disadvantaged communities to ensure that restoration efforts promote both environmental and social equity.

Collaboration with scientists, urban planners, NGOs, and citizen panels is essential to define a 'satisfactory level' of greening to be achieved by 2030. Indicators such as green space per inhabitant (m^2), percentage of green cover per district, and pollinator habitat connectivity can serve as benchmarks. This phase should also embed urban greening into planning instruments, including local master plans (PDMs), urban renewal areas (ARUs), and building codes. New regulations may, for example, require all new public buildings to include green roofs or walls. The overarching goal is to integrate greening into long-term urban development strategies and policy frameworks.

EXAMPLES

- *ESA's GTIF for Austria, which integrates multiple priority layers to enable cross-sectoral, data-driven decision-making.*
- *London's Living Roofs & Walls Supplementary Planning Guidance (SPG) operationalises planning targets with clear biodiversity-oriented design criteria, now mirrored by England's BNG metrics.*
- *Biotope/Green Area Factors (e.g., Berlin's BAF) provide a proven planning logic to weight typologies, enabling district level targets for rooftop and façade greening.*
- *Malmö's Green Space Factor illustrates how performance-based greening can be embedded through voluntary planning agreements in large redevelopment areas.*
- *Rotterdam's SCBA tool (LIFE@Urban Roofs) supports planning decisions by valuing multifunctional roof scenarios and allocating costs to the most suitable beneficiaries.*
- *Turin's proGIreg demonstrated district scale planning routes for green walls and water sensitive roof systems in urban regeneration.*

10.1.2.3 Policy and implementation phase

For green roofs and walls, financial incentives, tax reductions and grants should initially support retrofitting existing buildings with green infrastructure. New public and private buildings, especially schools and government facilities, should be required to integrate green roofs and green walls, prioritizing native and climate-resilient plant species to maximize ecological value. Local authorities should ensure that green roof and wall implementation aligns with existing nature protection programs and targets biodiversity-friendly designs.

EXAMPLES

- *Vienna offers a strong example of combining hard measures (building regulations, zoning, public building requirements) with soft measures (PPPs, subsidy programs) and technical guidance (e.g., GRF Vienna indicator, Guidelines), supported by data-driven planning and monitoring tools (Umweltgut, GTIF). However, the direct link to Vienna's Nature Restoration Law has not yet been established.*
- *Basel's combined building code and subsidy programmes mainstreamed roof greening with biodiversity standards, expanding city coverage tenfold in a decade.*
- *Amsterdam's rainwater ordinance and RESILIO programme demonstrate ordinance-driven delivery of blue-green roofs, scaled via PPPs into the social housing stock.*
- *Lisbon's CCB living walls and ETAR Alcântara green roofs demonstrate highly visible public implementation coupled with cost-benefit and well-being assessment.*
- *England's BNG alignment with green roof habitat scoring and sector training has accelerated implementation with verifiable ecological outcomes across public and private assets.*
- *Germany's FLL guidelines and Austria's ÖNORMs among others provide a robust technical backbone for design, construction and maintenance, widely referenced in EU implementation. Remote sensing and AI (for example GENTIAN) are being used in the UK to baseline and track roof habitat quality citywide, supporting BNG-aligned reporting.*

10.1.2.4 Monitoring and adaptive management

From 2031 onward, efforts should focus on monitoring and adaptive management. A six-year monitoring program, aligned with Article 14 of the NRR, should combine satellite imagery with field validation to track indicators such as total green space coverage, green space factors and biodiversity metrics (e.g. habitat connectivity and target species presence). The report highlights various monitoring options at both project and city levels, including tools currently in use (see Chapter 8). Transparency and citizen engagement should be prioritized, for example through public online dashboards displaying real-time progress. Public authorities will play a key role in communicating with citizens and businesses, as this phase may require adjustments of targets and strategies.

EXAMPLES

- *Vienna's Sargfabrik illustrates how adaptive management can be embedded in practice: a community-led approach that combines minimal intervention with expert input when needed, enabling long-term ecological resilience and social co-benefits. This model highlights the value of participatory monitoring and flexible maintenance protocols for biodiverse green roofs.*
- *The GROOVES programme established multi-season protocols on vegetation, arthropods and substrates, tying roof biodiversity to functional indicators and services.*
- *Helsinki integrated citizen science (iNaturalist) and user restoration surveys to track biodiversity and health co-benefits of green roof and façade systems.*
- *Lisbon's GRAVITY protocols mix instrumented inspections, PRS surveys and biodiversity observations to monitor living wall performance and user well-being.*
- *RESILIO roofs use IoT sensors and smart valves to adapt irrigation and retention, with field verified evaporation and energy balance measurements.*
- *Remote sensing and AI (for example GENTIAN) are being used in the UK to baseline and track roof habitat quality citywide, supporting BNG-aligned reporting.*

10.2 Guidance for policymakers and local administrations

10.2.1 Regulatory adaptation

It is essential to identify and remove outdated barriers, such as the former 'air tax' on green walls in Vienna, while harmonizing relevant policies across energy, water, climate resilience, biodiversity and health into a coherent implementation pathway. In light of current EU policy developments, Urban Nature Plans, Urban Wastewater Plans, renewable energy deployment, energy certification and renovation initiatives should proceed in an integrated manner. A cross-discipline and cross-department approach is central. Green roofs and walls must be recognized as central linking elements within this framework, ensuring that future policies on climate resilience, affordable housing, and the circular economy reinforce, rather than undermine, their role.

Integrating green roofs and walls into building codes at both national and local levels, is crucial, with early clarification of fire safety, structural standards and biodiversity requirements, to prevent delays in permitting. Mandating green roofs and walls for dense districts, new builds, and major renovations (as seen in Basel and Vienna) provides a strong regulatory foundation. In fact, the lack of standardized performance indicators at national level, for example insulation performance, shading performance, is a critical issue. It is strongly recommended that the development of standardized assessments, for example by incorporating insulation performance and summer cooling into the building energy performance certificate, is accelerated.

Policymakers should support the active development of biodiversity-friendly grassroots initiatives, networks and supply chains to overcome hurdles such as gaps in native seed mixes and plant availability. Communication should be transparent and proactive to build public trust and awareness of biodiversity goals.

10.2.2 Performance-based planning

Planning instruments should move beyond surface coverage to performance-based metrics. Enhanced Green Space Factors (e.g. GRFWien, Berlin's BAF) should integrate multifunctionality scoring, covering biodiversity, stormwater retention, cooling and social benefits. Simulation tools and remote sensing data can support decision-making and cost-benefit optimization.

Policymakers should kick-start implementation with funds and subsidies for planning and installation, explicitly including biodiversity and climate resilience indicators in eligibility criteria. This ensures ecological quality beyond aesthetic greening.

10.2.3 Funding and incentives

Offer combined subsidies for multifunctional systems (for example solar + green roof + biodiversity), covering additional costs for complex planning and technical integration. Incentives should reward designs that deliver multiple ecosystem services.

Beyond 'yellow' (energy), 'green' (biodiversity), and 'blue' (water management), the real economic value emerges when social functions ('red'), such as gardens and leisure spaces, are integrated, enhancing real estate value and strengthening the use and business case.

Support citizen-led projects with legal frameworks and financial aid. Empower communities with knowledge and organizational tools, as they are key drivers for biodiversity and long-term stewardship.

10.2.4 Risk management and maintenance

Require long-term maintenance plans and IoT-enabled monitoring for complex systems and large projects. These systems should feed adaptive management protocols, adjusting irrigation, plant palettes and habitat features, based on ecological feedback. Policymakers should develop contingency strategies for technical failures (for example irrigation sensors), but avoid overcomplication.

Natural habitats should be allowed to establish and evolve over time. Adaptive and educational maintenance should be promoted, potentially through community groups, and connect with science and technology providers for biodiversity expertise.

Policymakers should engage allies in unconventional sectors, insurance companies, facility managers, safety equipment providers, fire departments, and standardization institutes. Risk management strategies should leverage technical standards (for example hail resistance classification) to reduce insurance barriers and incentivize uptake.

10.2.5 Distributional considerations for equitable implementation

Green infrastructure implementation raises important questions about who benefits and who bears costs. Evidence suggests that without intentional design, green amenities can contribute to gentrification pressures as property values increase. Policy frameworks should consider mechanisms to ensure benefits reach under-resourced communities while protecting existing residents from displacement.

SUCCESSFUL APPROACHES

- *Prioritizing implementation in neighborhoods with limited green space access while including anti-displacement measures;*
- *Ensuring tenant protection where green infrastructure requirements might increase rents;*
- *Community ownership models (like Vienna's Grätzloase) that build local stewardship alongside physical infrastructure;*
- *Participatory governance ensuring marginalized voices meaningfully shape decisions, not just provide input.*

The community-led examples documented in this report (Sargfabrik, Grätzloase, Asphaltknackerinnen) demonstrate that alternatives to purely market-driven or top-down implementation can deliver both ecological value (Fig. 22) and social benefits.

Figure 22. Pollinators on a rooftop, Lower Austria.

Source: © Elisabeth Weiss-Tessbach.

10.3 Guidance for urban planners

10.3.1 Holistic design

Urban planners should integrate green roofs, walls, and open spaces into a single design logic to maximize multifunctional benefits, climate resilience, biodiversity, stormwater management, and social well-being. Performance-based tools such as GRFWien or the BAF help quantify ecological and economic value. Including social functions, like gardens and leisure areas, enhances acceptance and health benefits. Biodiversity-supportive approaches, such as AAD, should be embedded early in planning.

HOLISTIC DESIGN KEY ACTIONS

- *Use performance-based planning factors (GRFWien, BAF);*
- *Combine roofs, walls and open spaces for multifunctionality;*
- *Integrate social functions (gardens, leisure areas);*
- *Apply biodiversity-supportive design (HTA, AAD).*

10.3.2 Local adaptation

Designs should reflect local ecological conditions and climate resilience needs. It is recommended to use native species, locally sourced and recycled materials to align with circular economy principles. Also, further attention should be given to pollutants (e.g. biocides, PVC), energy-intensive system components, and non-recyclable system components.

Urban planners should plan for ecological succession and adaptive management, tolerating spontaneous vegetation where appropriate. HTA can guide species selection based on regional ecosystems.

LOCAL ADAPTATION KEY ACTIONS

- *Prioritize native, climate-resilient species;*
- *Use recycled substrates and local materials;*
- *Plan for succession and adaptive management;*
- *Align with regional habitat templates and Nature Plans.*

10.3.3 Stakeholder engagement

Successful projects depend on collaboration. Planners should foster PPP models and co-creation processes to ensure long-term stewardship. They should empower communities through citizen science and participatory maintenance programs, as seen in Vienna’s Grätzllabore. Transparent communication on biodiversity goals builds trust and accelerates uptake.

STAKEHOLDERS ENGAGEMENT KEY ACTIONS

- *Establish PPP and co-creation platforms;*
- *Empower communities for monitoring and maintenance;*
- *Use citizen science for biodiversity tracking;*
- *Communicate benefits clearly to all stakeholders.*

10.3.4 Innovation and knowledge transfer

Planners should embrace innovation and share lessons learned. They should document pilot projects to inform standards and guidelines. They should encourage cross-sector collaboration, linking energy, water, and biodiversity objectives, and integrate IoT-enabled monitoring for adaptive management. They should promote multifunctional roof concepts in planning frameworks.

INNOVATION AND KNOWLEDGE TRANSFER KEY ACTIONS

- *Document pilots to update standards;*
- *Encourage energy and green infrastructure synergies;*
- *Integrate IoT monitoring for adaptive management;*
- *Promote multifunctional roof concepts.*

11. Conclusions

Green roofs and green walls are no longer niche interventions. They are strategic NbS that help cities meet multiple objectives under the Nature Restoration Regulation, EU Biodiversity Strategy, Climate Adaptation frameworks and many other. This report demonstrates that these systems deliver significant co-benefits: they enhance biodiversity by providing stepstone habitats, mitigate heat stress, manage stormwater, improve energy efficiency, and support social well-being. Yet their uptake remains uneven across Europe due to regulatory gaps, financing challenges, and technical capacity.

To overcome these barriers, cities must embed green roofs and walls into planning instruments, building codes, and subsidy frameworks, ensuring biodiversity and climate resilience indicators are integrated from the outset. Performance-based planning tools and multifunctionality scoring systems can guide investment decisions and optimize ecological outcomes. Long-term success depends on adaptive management, supported by IoT-enabled monitoring and citizen engagement, as well as robust maintenance protocols that allow natural succession while safeguarding safety and functionality. Cities and Municipalities are in the center of those activities, while cross-department collaboration and multi-level integration is the key.

Innovation and cross-sector collaboration, linking energy, water and biodiversity objectives, will be critical for scaling. Circular material use, multifunctional roof concepts (biodiverse-solar, blue-green systems, neighbourhood space), and participatory governance models offer pathways to mainstream these solutions. By treating rooftops and façades as ecological assets rather than residual spaces, Europe can transform its urban fabric into a resilient, biodiverse, and socially inclusive landscape (Fig. 23), delivering on restoration targets while creating healthier, more livable cities.

Figure 23. Orchids blossoming on a green roof, Switzerland.

Source: © Stephan Brenneisen.

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List of abbreviations and definitions

Abbreviations	Definitions
AAD	Animal Aided Design
AI	Artificial intelligence
ARU	Urban Renewal Area
BAF	Biotope Area Factor
BfN	German Federal Agency for Nature Conservation
BMS	Building Management System
BNG	Biodiversity Net Gain
BuGG	German Association of Building Greening
CCB	Cultural Centre of Belém
CMW	Community Weighted Mean
CSR	Competitors, Stress-tolerators, Ruderals
CHF	Swiss Francs
DIY	Do-It-Yourself
ECMWF	European Centre for Medium-Range Weather Forecasts
EED	Energy Efficiency Directive
EFB	European Federation of Green Roof and Wall Associations
EPBD	Energy Performance of Buildings Directive
ESA	European Space Agency
ESG	Environmental, Social, and Governance
ETAR	Wastewater Treatment Plant
FD	Functional Diversity

Abbreviations	Definitions
FDis	Plants Functional Dispersion
FLL	Research Society for Landscape Development and Landscape Construction
GENTIAN	Green Infrastructure Evaluation Tool for Urban Nature-Based Solutions
GLA	Greater London Authority
GRFWien	Vienna Green Space and Stormwater Management Factor
GTIF	Green Transformation Information Factory
HH&W	Human Health and Well-being
HTA	Habitat Template Approach
HVAC	Heating, Ventilation and Air Conditioning
InKA	Infrastructure Adaptation to Climate Change
IoT	Internet of Things
LCC	Life Cycle Costing
LCA	Life Cycle Assessment
NbS	Nature-based Solutions
NDVI	Normalized Difference Vegetation Index
NGO	Nongovernmental Organization
NRR	Nature Restoration Regulation
PD	Phylogenetic Diversity
PDM	Passive Design Measure
PET	Physiological Equivalent Temperature
PIISA	Piloting Innovative Insurance Solutions for Adaptation

Abbreviations	**Definitions**
PPP	Public Private Partnership
PRS	Perceived restorative scale
PV	Photovoltaic
RMQS	French National Soil Monitoring Scheme
SCBA	Societal Cost Benefit Analysis
SPG	Supplementary Planning Guidance
SROI	Social Return on Investment
SuDS	Sustainable Urban Drainage Systems
TSS	Total Suspended Solids
TUM	Technical University of Munich
UHIE	Urban Heat Island Effect
UWWTD	Urban Wastewater Treatment Directive
VGS	Vertical Greenery Systems
WSUD	Water-Sensitive Urban Design
ZHAW	Zurich University of Applied Sciences

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Annexes

Annex 1: Survey used for collecting case studies

Green Roofs & Green Walls – 1st Collection of Case Studies

Please use the form below to propose potential case studies for later in-depth review, to support the European Commission's request for a practical guide on the local implementation of green roofs and walls, based on lessons from European experiences.

A case study is understood here as a concrete project or initiative focused on the design, construction, or implementation of green roofs and/or green walls. Cases can be identified from your own professional experience or through your professional network.

Please fill in as many as possible of the fields below.

Expert name

(Full name of the person submitting the case)

Project name

(Official or working title of the case study)

City and Country

(Location of the project)

URL links

(Please include any relevant link to the case study and add a short explanation of its content.)

Green roof & green wall's size

(Please indicate either the approximate size in m²)

Green roof & green wall's spatial scope

(Please indicate whether it is local/single intervention, neighbourhood, district, or city scale.)

Green roof & green wall's setting

(Please select among the options: urban, peri-urban, others)

System type

Please select among the options (multiple choices are allowed). Please upload any pictures to the folder at this link.

Options: Extensive green roof / Semi-intensive green roof / Intensive green roof / Ground-Based Climbers (Self-Climbers) / Ground-Based Climbers (Climbing Support) / Planter-Based Vertical Green / Living Wall /Others.

Implementation process

(Please select among the options: Top-down approach / Bottom-up approach / Both / Unknown, others.)

Were there any design features or monitoring efforts to support or assess biodiversity outcomes after implementation?

Please select among the options: Yes / No/ Unknown

Did the case study involve a participatory process?

Please select among the options: Yes / No / Unknown

Annex 2: Full list of collected case studies from the expert group survey

N.	Project name	City	Country	System typology	Selected
1	De Doelen	Rotterdam	The Netherlands	Extensive to semi-intensive green roof (blue-green roof)	Yes
2	DakAkker	Rotterdam	The Netherlands	Intensive green roof	
3	Hofbogenpark	Rotterdam	The Netherlands	Intensive green roof	
4	Pakt	Antwerpen	Belgium	Intensive green roof (urban agriculture)	Yes
5	De Groene Kaap	Rotterdam	The Netherlands	Intensive green roof	
6	Peperklip	Rotterdam	The Netherlands	Extensive green roof	
7	St. Pauli Bunker	Hamburg	Germany	Intensive green roof	
8	P-hus Anna	Malmö	Sweden	Living Wall	Yes
9	Aroma Toit	Paris	France	Semi-intensive green roof	
10	Paris Tech	Paris	France	Semi-intensive green roof	
11	Musée du quai Branly	Paris	France	Living Wall	
12	Calouste Gulbenkian Green Roofs	Lisbon	Portugal	Intensive green roof	Yes
13	Turku Energia green roof: article case study.	Turku	Finland	Green roofs	
14	ETAR Alcântara	Lisbon	Portugal	Semi-intensive green roof	Yes
15	CCB Living Wall	Lisbon	Portugal	Living Wall	Yes
16	The Pulse	Amsterdam	The Netherlands	Intensive green roof	
17	Rooftop garden Erasmus MC	Rotterdam	The Netherlands	Intensive green roof	
18	CWC city water circle Open 011	Torino	Italy	Intensive green roof	
19	proGIreg - green walls	Torino	Italy	Living Wall	
20	David Attenborough Building	Cambridge	UK	Extensive green roof	Yes
21	Rubens at the Palace Hotel	London	UK	Living Wall	Yes
22	MA 48- Public Building Refurbishment	Vienna	Austria	Living Wall	Yes
23	Sargfabrik Vienna	Vienna	Austria	Semi-intensive to intensive green roof	Yes
24	Solargreenroof Maildistribution service Vienna	Vienna	Austria	Extensive green roof and Photovoltaic panels	Yes
25	Biotope City Vienna	Vienna	Austria	Extensive to intensive green roofs, green walls	Yes
26	Klinikum 2 University Hospital Basel	Basel	Switzerland	Semi-intensive green roof	Yes

N.	Project name	City	Country	System typology	Selected
27	BVB Tramdepot	Basel	Switzerland	Extensive green roof	
28	Cascina val del prete	Cuneo	Italy	Extensive green roof	
29	ENEA - Blue-green roof	Rome	Italy	Extensive green roof	
30	ENEA – Energy School (roof)	Rome	Italy	Extensive green roof	
31	ENEA – Energy School (wall)	Rome	Italy	Planter-Based Vertical Green	
32	Ex-Swisscom	Giubiasco	Switzerland	Extensive green roof	Yes
33	HIM co Industry	Fossò	Italy	Semi-intensive green roof	
34	Imperatore Federico - Tetto A	Palermo	Italy	Semi-intensive green roof	
35	Imperatore Federico - Tetto B	Palermo	Italy	Semi-intensive green roof	
36	Liceo scientifico Keplero	Rome	Italy	Extensive green roof	
37	Manarola parking	Manarola	Italy	Semi-intensive green roof	
38	Seewasserwerk Moos - Roof 1	Zurich	Switzerland	Semi-intensive green roof	
39	Leher Wiesen - Turnhalle	Hannover	Germany	Semi-intensive green roof	Yes
40	Werkhof Scheidegg - Biosolar	Winthertur	Switzerland	Extensive green roof	
41	IGNITION NBS Living Lab	Manchester	UK	Living Wall, Extensive green roof	Yes
42	The Hellenic Treasury	Athens	Greece	Extensive green roof	
43	Green facade in Opole	Opole	Poland	Green facade	
44	Benaguasil	Valencia	Spain	Extensive green roof	Yes
45	The Greenest of the Green block	Helsinki	Finland		Yes
46	Noah's Ark Barnet London	London	UK	Biosolar green roof	Yes

Annex 3: List of guiding complementary questions used to analyse selected cases.

Green roof and green wall typologies and technical features

- Typology (select one):
  - Green roofs (GR): Extensive / Semi-intensive / Intensive
  - Green walls (GW): Ground-based climbers (self-clinging / supported) / Planter-based vertical greenery / Living walls
- Total system weight - combined weight per square meter (kg/m^2) of all the components of the GR/GW system when fully saturated;
- Includes biodiversity-supporting design elements? Yes/No → If yes, briefly describe the design elements and refer to potential design frameworks if applicable.
- Combined with solar systems? Yes/No/Maybe → If yes, briefly describe the integration method.
- Construction type:
  - New construction — Yes/No/Maybe
  - Retrofitting — Yes/No/Maybe

Shading: the extent to which the green roof or wall reduces sunlight exposure of a building surface, impacting thermal regulation, energy savings, and plant health;

- What metrics or simulation tools were used for quantifying the shading effect of GR/GW on solar radiation and surface temperature?
- Did the plant density influence the shading performance of GR/GW systems throughout different seasons?
- How do shading benefits translate into measurable reductions in cooling loads or energy consumption for buildings?

Accessibility: ease of access for installation, routine maintenance, inspections, and repairs, which influences safety and upkeep costs;

- How does the GR/GW location affect it accessibility for routine maintenance and inspections?
    - Designed for safe and routine access (e.g. dedicated walkways, guardrails, and maintenance zones integrated into design)
    - Accessible only with special equipment (e.g. Safe access routes and anchors provided, limited points or ladders, restricted movement area)
    - Access restricted (e.g. access requires temporary scaffolding or specialized safety gear)
- How do local safety regulations or standards influence the design of accessible green roof or wall systems?
- Are there innovative technologies or remote monitoring tools that can reduce the need for physical access to GR/GW installations?

Irrigation needs: The amount and frequency of water required to sustain healthy plant growth on the green roof or wall, influenced by plant species, climate, substrate, and system design.

- What is the GR/GW system weight (kg/m^2 when saturated)?
- How do structural load limitations influence the selection of green roof or wall systems for retrofit versus new construction projects?
- What advances in lightweight substrates or drainage materials have most significantly reduced total system weight without compromising performance?
- How does the moisture retention capacity of the substrate affect the total saturated weight, and how do designers typically balance this with stormwater management goals?
- Are there standard testing or certification methods to verify total system weight and load performance in practice?

Benefits and co-benefits to the urban environment

Biodiversity enhancement metrics/outcomes: measurements on how GR/GW support urban ecological resilience and conservation of local flora and fauna (e.g. species richness, pollinator activity, or habitat connectivity).

- What indicators or metrics were used for assessing biodiversity outcomes in GR/GW systems (e.g., species richness, abundance, habitat value)?
- How does the system typology (e.g., intensive vs. extensive roofs, living wall vs. green facade) influence potential for supporting biodiversity?
- What design features most effectively promote pollinator activity?
- How do maintenance practices (e.g., irrigation regimes, vegetation trimming, substrate type) affect long-term biodiversity performance?
- Are there any standardized methods or monitoring protocols used to evaluate habitat connectivity or ecological value?

Urban cooling and microclimate regulation: assessments of GR/GW ability to reduce ambient temperatures through shading and evapotranspiration, helping mitigate the urban heat island effect and improve thermal comfort at the building and neighbourhood scale.

- How do GR/GW systems compare to conventional building surfaces in reducing surface and ambient air temperatures?
- What parameters or tools were used to quantify the cooling effect (e.g., surface temperature monitoring, thermal imaging, microclimate modeling)?
- How significant is the role of plant selection and evapotranspiration rates in enhancing cooling performance?
- To what extent do GR/GW installations contribute to reducing the urban heat island effect beyond the individual building scale?
- What design or maintenance challenges limit the consistency of cooling benefits over time?

Stormwater management performance: analysis of how GR/GW capture, retain and slows down rainwater runoff (e.g. runoff reduction percentage, peak flow delay).

- What are the key hydrological parameters that were assessed when evaluating GR/GW stormwater performance (e.g., runoff volume reduction, detention time, peak flow delay)?
- How does the substrate depth, material composition, and drainage layer design influence stormwater retention capacity?
- What monitoring approaches or modeling tools are most effective for quantifying stormwater performance under variable rainfall conditions?
- How do different green roof typologies perform under extreme precipitation events?
- What role does vegetation type play in enhancing infiltration or evapotranspiration as part of stormwater management?
- How can the long-term stormwater management performance of GR/GW systems be affected (e.g. due to substrate compaction, aging materials, or plant succession)?

Social and health co-benefits: evaluation of positive effects of GR/GW on human well-being (e.g. stress reduction, attention restoration, improved air quality, noise buffering) and increased access to green space, which support mental and physical health, especially in dense urban areas.

- What types of social or health benefits are most frequently reported or measurable from GR/GW projects (e.g., stress reduction, noise buffering, air quality improvement)?
- What methods were used to assess/quantify these co-benefits (e.g. through direct measurement, surveys, or modeling)?
- How does user accessibility or visibility of GR/GW spaces influence their social or psychological value?
- Are there particular design elements (e.g., seating areas, visual openness, sensory diversity) that enhance user well-being outcomes?
- What evidence or studies have you encountered that link GR/GW presence to measurable public health improvements in urban settings?
- How do cultural or demographic factors influence the perceptions and benefits of GR/GW?

Long-term economic returns: financial value generated over time through energy savings, increased property value, extended roof lifespan, reduced stormwater fees, and potential access to green incentives or credits, contributing to lifecycle cost-efficiency.

- How is evaluated the lifecycle cost-efficiency of GR/GW systems compared to conventional alternatives?
- What financial metrics were used for assessing economic returns (e.g., payback period, net present value, avoided costs)?
- How were the non-market benefits (e.g. ecosystem services, well-being or health benefits) accounted for in their economic assessments?
- Which benefits (e.g. energy savings, increased property value, or reduced stormwater fee) provide the greatest long-term financial return?
- What are the most significant economic barriers or risks to large-scale adoption of GR/GW systems?

Governance and policies

Policy and regulatory hurdles: legal, zoning, and administrative barriers that can delay or discourage the implementation of GR/GW (e.g. outdated building codes, lack of standards for GR/GW, bureaucratic permitting processes, limited recognition of their impact in stormwater regulations)

- What are the most significant policy or regulatory barriers currently hindering the widespread adoption of GR/GW systems?
- How do existing building codes or urban design guidelines facilitate or restrict the integration of GR/GW on buildings?
- Are there specific gaps in national or local standards (e.g., technical guidelines, load-bearing criteria, or fire safety provisions) that complicate approval processes?
- How do permitting and inspection procedures impact project timelines or costs for GR/GW installations?
- To what extent are GR/GW systems recognized in stormwater management or sustainability regulations (e.g., credit systems, runoff reduction targets)?
- What policy reforms or institutional changes would most effectively accelerate mainstream adoption of GR/GW technologies?

Multi-stakeholder coordination models: coordinated input from multiple stakeholders (e.g. public-private partnerships, community co-design approaches, and interdepartmental working groups).

- What coordination structures (e.g., interdepartmental task forces, cross-sector partnerships) have proven most effective in supporting GR/GW implementation?
- How was ensured the alignment between public agencies, developers, designers, and maintenance operators throughout a project's lifecycle?
- What are common sources of conflict or miscommunication among stakeholders, and how are they typically resolved?
- Can you share examples where community participation or co-design approaches improved project acceptance or long-term stewardship?
- How does leadership or governance structure influence the success of multi-stakeholder coordination in GR/GW initiatives?
- What lessons have emerged from public–private partnership models for GR/GW development and maintenance?

Supply-chain and local sourcing constraints: constrains that main lead to increased costs or project delays (e.g. limited availability of specialized materials or native plant species suitable for GR/GW).

- What supply-chain challenges most frequently affect GR/GW projects (e.g., lack of specialized components, plants, or certified installers)?
- How does the availability of locally sourced or regionally adapted materials influence project sustainability and cost-effectiveness?
- Have disruptions in supply (e.g., due to climate variability, logistics, or market limitations) impacted project delivery timelines?
- What strategies have been used to strengthen local production networks or stimulate demand for GR/GW-related materials and expertise?
- How do you evaluate the trade-offs between imported specialized materials and locally available substitutes?
- Are there policy or procurement mechanisms that could improve local sourcing and reduce dependency on external suppliers?

Risk allocation: contracts and implementation frameworks with clear identification of parties responsibility for different types of project risks (e.g. structural failure, plant mortality, waterproofing breaches, or underperformance in stormwater retention).

- How are responsibilities for key project risks (e.g., waterproofing failure, structural load issues, plant mortality) typically distributed among project partners?
- Which project delivery models (e.g., design-build, EPC, performance-based contracting) best support fair and clear risk allocation for GR/GW systems?
- How do insurance providers or regulators perceive and assess risks associated with GR/GW?
- What are common disputes or grey areas regarding liability for performance under real-world operational conditions?
- How do you believe that can be ensured that risk allocation frameworks remain balanced over the long term, especially as system maintenance needs evolve?
- Are there examples of standardized contractual clauses or templates that effectively manage risk allocation in GR/GW projects?

Liability and warranties: legal responsibilities and performance guarantees in case of damage or failure of the GR/GW system or its layers (e.g. waterproofing membranes, plants)

- How are warranties typically structured for different GR/GW system components (e.g., waterproofing membranes, drainage layers, vegetation)?
- What duration and coverage are considered best practice for performance warranties in GR/GW installations?
- How are liability and warranty responsibilities divided between product manufacturers, installers, and building owners?
- In cases of system failure or underperformance, what mechanisms exist for dispute resolution or financial compensation?
- How is evaluated or verified the performance to ensure warranty compliance over time (e.g., through inspection, monitoring, or certification)?
- Are there emerging insurance or warranty models specifically tailored for GR/GW systems?

Case-proven mitigation strategies: tested strategies used to overcome implementation challenges in existing GR/GW projects (e,g., policy incentives - density bonuses or green roof bylaws, modular green roof systems to ease installation, training programs to address maintenance gaps, or performance-based contracts to ensure ecological outcomes.

- What practical measures have been implemented or observed that successfully address common policy, technical, or logistical barriers to GR/GW deployment?
- What incentive mechanisms (e.g. Tax reductions, subsidies, sustainability certification) that have proven particularly effective?
- How have modular or pre-grown GR/GW systems helped reduce installation complexity or time?
- What capacity-building or training initiatives have improved maintenance quality or system longevity in your experience?
- Have performance-based contracts or outcome-linked incentives been used to ensure ecological or hydrological targets are met?
- Based on your experience, what combination of regulatory, financial, and technical strategies offers the most robust pathway to scalable implementation?

Maintenance, monitoring and adaptative management

Biodiversity monitoring protocols: use of standardized methods and procedures (e.g. field methods, remote sensing or citizen science) to assess, track, and report changes in biodiversity over time to better understand the health of ecosystems, evaluate the effectiveness of conservation efforts, and informing policy decisions.

- What standardized methods or protocols are used to monitor biodiversity on GR/GW systems (e.g. surveys, pitfall traps, pollinator counts, vegetation sampling)?
- How frequently are biodiversity assessments conducted, and what temporal scales are most informative for detecting ecological trends?
- Have you integrated remote sensing or drone-based technologies to complement field-based biodiversity monitoring?
- How do you ensure data consistency and comparability across sites and over time?
- What indicators (e.g., species richness, pollinator visitation rates, habitat complexity) have proven most reliable in reflecting ecological performance?
- How is biodiversity data used to inform policy decisions, adaptive management, or certification schemes?
- Are there opportunities to involve citizen scientists, community groups, or educational institutions in biodiversity monitoring efforts?
- What challenges have you encountered in maintaining long-term biodiversity datasets for urban greening systems?

Inspection and health checks: identify how often the green roof/green wall is inspected (e.g. seasonal, annual, or long-term intervals)

- How frequently should GR/GW systems ideally be inspected to ensure optimal performance and safety (e.g., monthly, seasonal, or annual intervals)?
- What are the key elements typically checked during inspections (e.g., vegetation health, irrigation system functionality, drainage performance, waterproofing integrity)?
- Who is usually responsible for conducting inspections—maintenance contractors, building managers, or specialized consultants?
- How are inspection findings documented and used to inform maintenance scheduling or system upgrades?
- What are common signs of system degradation or early warning indicators of potential failure?
- How do inspection intervals vary depending on system typology (extensive vs. intensive roofs; living wall vs. green facade)?

- What digital maintenance logs, inspection software, or other documentation tools are used to track GR/GW system conditions over time?
- How do regulatory or warranty requirements influence inspection frequency and reporting protocols?

Iot and remote sensing for performance tracking: use of a network of smart sensors and devices (e.g. sensors, meters, etc.) installed to monitor and control GR/GW conditions in real-time and determine their ecological health and/or the quality of the surrounding environment (e.g. soil moisture, air quality/temperature/humidity/acoustic sensors).

- What types of IoT sensors or remote monitoring systems are currently being deployed in GR/GW installations (e.g., soil moisture sensors, temperature/humidity meters, air quality monitors)?
- How do real-time monitoring technologies improve system management compared to conventional manual inspections?
- What parameters are most critical to track continuously for ecological and technical performance evaluation?
- How are IoT data integrated with building management systems (BMS) or smart city platforms for holistic environmental monitoring?
- What are the main technical or financial barriers to widespread adoption of sensor-based monitoring systems?
- How do you ensure data reliability, calibration accuracy, and long-term maintenance of monitoring equipment?
- What remote sensing technologies are being used (e.g., thermal imaging, NDVI, satellite data) to assess vegetation health or detect system anomalies?
- How can IoT-enabled data inform decision-making on irrigation scheduling, maintenance timing, or adaptive management?

Adaptive management based on ecological feedback: structured or flexible decisions are adapted over time based on what is learned from monitoring ecological responses of GR/GW (e.g. changing weather conditions, pests or diseases outbreaks, plant grow cycles, environmental changes).

- How is monitoring data (e.g., from biodiversity assessments or sensor systems) used to inform adaptive management decisions for GR/GW systems?
- What kinds of management adjustments are most commonly implemented in response to ecological feedback (e.g., changes in plant palette, irrigation regimes, or pest control strategies)?
- How flexible are maintenance protocols to accommodate environmental variability such as droughts, heavy rainfall, or heatwaves?
- How are established formal feedback loops or decision-making frameworks linking monitoring results to management actions?
- What indicators trigger adaptive interventions (e.g., vegetation stress thresholds, pest/disease occurrence, substrate compaction levels)?
- How are balanced the costs, ecological outcomes, and long-term system performance when making adaptive changes?
- Are there successful examples of adaptive management frameworks improving the ecological resilience of GR/GW projects?
- How are being documented and shared lessons learned from adaptive management to refine future project designs or maintenance strategies?

Financial and market conditions

Cost breakdown: costs of the design, materials, installation and maintenance of the GR/GW system.

- What are the main cost components associated with GR/GW projects in your experience (e.g., design, materials, installation, maintenance, monitoring)?
- How does system typology (extensive vs. intensive roofs; living wall vs. green facade) affect the overall cost distribution?
- How do maintenance and replacement costs evolve over the system's lifespan, and how are these factored into initial project budgeting?
- Were observed any regional or market-specific variations in cost drivers (e.g., labor rates, plant availability, import dependencies)?
- What tools or models are used to estimate and communicate lifecycle costs to clients or stakeholders?
- How do warranty or performance guarantee requirements influence upfront and long-term cost structures?
- What strategies are effective in reducing capital or operational costs without compromising system performance?

Biodiversity: focused funding streams (grants, green bonds) or incentives for the implementation of GR/GW to promote biodiversity.

- What types of funding mechanisms or incentives are currently available to support GR/GW projects that prioritize biodiversity outcomes (e.g., grants, green bonds, tax credits)?
- How effective have biodiversity-linked funding schemes been in promoting the ecological design of GR/GW systems, as opposed to purely aesthetic or stormwater-driven designs?
- Are biodiversity metrics (e.g., species richness, habitat connectivity) commonly required or rewarded in funding applications?
- How do project teams demonstrate measurable biodiversity benefits to qualify for such funding?
- Are there any successful examples of biodiversity-focused GR/GW financing?
- How can existing financial instruments (e.g., ESG investments, green infrastructure funds) be better tailored to support ecological outcomes in urban greening projects?
- What role do private developers play in leveraging biodiversity-oriented incentives for project co-financing?
- What are the key barriers to scaling biodiversity-linked financial support mechanisms for GR/GW systems?

Public-private partnership models: collaborative arrangements between government entities and private sector actors to fund, design, build, maintain, or operate projects that deliver public benefits.

- What forms of PPP arrangements have been most effective in delivering GR/GW projects with long-term maintenance commitments?
- How are financial responsibilities and risks typically divided between public and private partners in such models?
- What incentives or guarantees (e.g., performance payments, cost-sharing) have proven successful in encouraging private sector participation?
- How do PPP models ensure that ecological or social benefits—such as biodiversity gains or community access—are maintained throughout the project lifespan?
- Can you cite examples of PPPs that have integrated green infrastructure into broader urban development or resilience strategies?

- How does government leadership (e.g., through policy frameworks or demonstration projects) influence market confidence and investment in GR/GW initiatives?
- What are the most common challenges in aligning public objectives (e.g., sustainability, equity) with private sector profitability?
- How could PPP frameworks be adapted to improve accountability, transparency, and long-term performance of green infrastructure assets?

Cost-benefit projections (20-and 50-year horizons): evaluation of long-term economic, environmental, and social benefits in monetary terms.

- What methodologies or models do you use to assess the long-term economic performance of GR/GW systems (e.g., cost–benefit analysis, lifecycle assessment, ecosystem service valuation)?
- How are indirect or non-market benefits—such as energy savings, improved air quality, and health co-benefits—quantified over extended time horizons?
- How do projected maintenance, plant replacement, or retrofitting costs affect 20- and 50-year financial forecasts?
- To what extent do long-term benefits offset initial capital costs under realistic market and climate scenarios?
- What discount rates or financial assumptions are typically used when projecting returns from GR/GW systems over multi-decade periods?
- How are co-benefits such as property value increases or avoided stormwater fees integrated into economic models?
- Have you evaluated or observed differences in projected payback periods between public-sector and privately financed projects?
- How do uncertainties (e.g., climate change impacts, policy shifts, or market volatility) influence long-term cost–benefit projections for GR/GW investments?

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