



Contribution of nature-based solutions (NbS) to resilience - A review of European projects between 2014 and 2023

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ABSTRACT

Climate change has a global impact, particularly in urban areas. Nature-based Solutions (NbS) are gaining prominence as an important alternative, harnessing natural processes to deliver socio-economic and environmental benefits, particularly in urban and peri-urban areas, owing to their multifaceted nature. In Europe, NbS are being primarily explored in urban environments to enhance resilience to extreme climatic events. This study consisted of a systematic review of 66 projects funded by the European Union (EU) between 2014 and 2023, conducted in accordance with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), a set of standards aimed at improving the quality and transparency of systematic reviews. The review was carried out through the analysis of EU research and development repositories, based on criteria including funding period, project description, geographical location, typology, methods adopted in each project, and the main challenges identified, which underscore the urgency of innovative solutions to manage natural systems in urban environments. The qualitative and quantitative analysis indicates the wide geographical distribution of the projects, with significant applications in countries such as Spain ($n = 76$), Italy ($n = 40$), France ($n = 36$), Germany ($n = 29$), and Portugal (with $n = 28$). Projects were categorized according to their purpose, methodology, and technologies employed, highlighting a diversity of approaches, sufficiently replicable to ensure feasibility in future projects that promote urban sustainability and adaptation to climatic adversities.

The urban challenges faced in the implementation of the projects analysed include issues related to the deployment and replication of solutions, community behavioural change, collaboration between different stakeholders, and funding. Furthermore, the various target groups involved reflect a collaborative approach to the co-creation of NbS, aimed at maximizing benefits and strengthening community resilience, with a particular focus on government entities ($n = 50$),

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citizens ($n = 41$), the scientific community ($n = 26$), the business community ($n = 21$), and civil society/NGO ($n = 13$), thereby achieving the objectives set. This study underscores the importance of NbS as a tool to address social, economic, and environmental challenges, particularly in cities, contributing to the development of more resilient communities. However, in order to effectively respond to the Sustainable Development Goals (SDGs), greater efforts are required to ensure the inclusion of NbS and a broader variety of measures in public policies, given that 2030 has been set as the target year for achieving the SDGs.

1. Introduction

Nature-based Solutions (NbS) can be regarded as strategies grounded in natural processes to address challenges and provide social, environmental, and economic benefits in an integrated manner (Fraga and Sayago, 2020). These approaches, which may be considered tools for adaptation, resilience, and ecosystem mitigation to restore benefits, gained prominence as a concept in the late 2000s, accompanying the growth of initiatives to tackle environmental challenges imposed by the “development of modern society”. The main areas where NbS stand out and provide alternatives include climate change mitigation and adaptation (Seddon et al., 2020), biodiversity conservation and the restoration of degraded ecosystems (Cohen-Shacham et al., 2016), the improvement of water quality and availability (Raymond et al., 2017), and the recovery of degraded soils (Seddon et al., 2020), in response to the various shifts throughout the “development of production” that have resulted in negative impacts on agricultural, industrial, and urban practices, such as soil compaction and the depletion of nutrients and organic matter (Ribeiro et al., 2025a).

NbS have gained recognition from international institutions, most notably from the European Union (EU), which has been a pioneer in identifying them as key instruments for climate change adaptation (Blesh and Barrett, 2006; Kabisch et al., 2016; Davies et al., 2021). These NbS measures are particularly promoted in urban and peri-urban environments, since urban systems involve multiple areas requiring a transition towards sustainability, such as access to nature, transport, energy and decarbonization issues, and rapid population growth (Ribeiro et al., 2025a). This includes Blue-Green Infrastructure (BGI), such as the creation of urban green spaces, rain gardens, vegetated swales, green roofs, and pocket parks (Alexandri and Jones, 2008), ecological restoration and conservation practices, and hybrid solutions integrating natural and built elements, with the aim of reducing cities vulnerability to extreme climatic events and biodiversity loss.

Moreover, NbS can mitigate others risk factors, such as vulnerability to coastal flooding (Debele et al., 2023), reduced air quality due to pollution (Theophilo et al., 2021), vulnerability to Urban Heat Island (UHI) caused by a lack of green areas and increased impermeable land cover (Brandimarte and Borgström, 2024), declining potable water quality (Biswal et al., 2022), and increased soil erosion in both urban and rural areas (Keesstra et al., 2018). These integrated approaches broadly strengthen both community and ecological resilience (Kumar et al., 2020a,b; Turner et al., 2022; Debele et al., 2023).

The rise in average global temperature and the intensification of extreme weather events are highlighted in the 2023 Climate Change Synthesis Report, led by the Intergovernmental Panel on Climate Change (IPCC Homepage,), reinforcing the urgency of adopting and prioritizing such approaches. NbS are intrinsically linked to ecosystem services, as they promote the provision of regulatory services, such as flood control and extreme event management, supporting services, including biodiversity conservation, and cultural services, through the creation of recreational spaces and awareness-raising (Liu et al., 2021; Cheng and Li, 2024). In this way, they contribute to sustainability and urban resilience by restoring and enhancing essential ecosystem functions. Within this context, NbS should be integral to the global sustainability agenda and constitute essential guidelines for tackling climate change and achieving the Sustainable Development Goals (SDGs) (Dumitru and Wendling, 2021).

A significant advance in this field has been the institutional definition of NbS. The European Commission (EC) describes them as interventions inspired and supported by nature, with the capacity to generate environmental, social and economic benefits simultaneously, aiming to enhance climate resilience in cities, natural or semi-natural landscapes, and coastal areas (Wild et al., 2020). Similarly, the United Nations Environment Assembly (UNEA, 2022) adopted a globally accepted definition, proposed in Resolution 5/5, the first to be globally agreed upon, characterizing NbS as actions aimed at protecting, conserving, restoring, and managing natural or modified ecosystems, with the objective of addressing social-economic and environmental challenges while simultaneously ensuring benefits for human well-being, ecosystem services, and biodiversity conservation. These definitions consolidate the role of NbS as efficient alternatives adaptable to local specificities, while also reinforcing their economic viability compared with conventional engineering approaches.

In Europe, the integration of NbS into public policy has gained momentum. Examples of policy instruments include the European Green Deal, adopted in 2019, which positions NbS as central pillars for achieving climate neutrality by 2050, highlighting their relevance for carbon emission mitigation and adaptation to extreme climatic events. This framework sets specific guidelines for the preservation and restoration of critical ecosystems, particularly in urban and peri-urban settings, as well as for circular economy initiatives (European Commission, 2019). The New European Bauhaus, on the other hand, emphasizes NbS as transformative elements for sustainable design and planning, combining aesthetics, landscape, social inclusion, and ecological sustainability in projects integrating green infrastructure and technological innovation. These policies not only underscore the role of NbS in climate change mitigation and adaptation but also reinforce their contribution to water security, biodiversity promotion, and social cohesion (European Commission, 2021). The Nature Restoration Law, adopted in 2022, complements these initiatives by proposing binding targets for the restoration of degraded ecosystems and enhancing the resilience of ecosystem services by 2030 (European Commission,

2022). Despite these advances, the practical application of NbS remains fragmented, particularly in urban settings, due to conceptual ambiguities and challenges in implementation and monitoring (Sowińska-Swierkosz and García, 2022).

However, the practical application of NbS in urban environments remains unclear and fragmented. Although the introduction of IUCN standards in 2020 has addressed the lack of theoretical clarity with a global benchmark, difficulties remain in implementing NbS. These include local adaptation challenges, since global criteria may not capture all nuances and local needs due to territorial complexity. Furthermore, implementing a rigorous and measurable monitoring system, as required by the eighth criterion, may be demanding for many projects, especially those with limited resources.

The EU's ambition to lead globally in NbS knowledge has been supported by significant investments in research and innovation (European Commission, 2015; Davies et al., 2021; Oppla, 2024). In this regard, the EU has invested in research and innovation programs such as Horizon 2020 and Horizon Europe, aimed at promoting the development, experimentation, and dissemination of NbS (European Commission, 2023; Zenodo, 2024).

Nevertheless, despite these efforts, important gaps remain in the implementation and replication of efficient solutions, as well as in behavioural change and community engagement. Two types of knowledge challenges are widely recognised by various authors and institutions at the international level: technical design and the evolution of effectiveness (Castelo et al., 2023; Network Nature, 2024; Ribeiro et al., 2025b). Beyond NbS-specific gaps, some knowledge deficiencies are linked to adaptation itself, despite substantial progress in recent years. Castelo et al. (2023) identify four major knowledge gaps in the use of NbS for urban adaptation: uncertainties regarding future climate, challenges in resilient technical design, governance gaps, and the need for better effectiveness evaluations.

Fig. 1 summarizes the evolution of references to NbS and the main contributions of different authors over time. This figure provides a panoramic view, highlighting the most relevant references, conceptual milestones, and the evolution of discussions around NbS.

Recognising that NbS are fundamental to achieving the EU's sustainability goals, the question this section seeks to address is the following: *What are the most recent and important Nature-based solutions (NbS) initiatives and practices implemented or funded by the EU in urban and peri-urban areas with a focus on urban resilience?*

This study proposes a detailed analysis of EU-funded NbS projects, focusing on urban environments and the transition towards smart and sustainable cities. By reviewing and categorizing these projects, we aim to identify trends, challenges, and opportunities associated with the implementation of NbS, particularly in urban contexts. The uniqueness of this article lies in the breadth of the analysis carried out, which identifies and characterizes projects funded by the EU between 2014 and 2023, including both large-scale programs and transnational initiatives. This investigation differs from earlier studies, such as that of Bona et al. (2022), by adopting a broader scope and by also considering the application of NbS outside the European continent, namely in countries such as China, Turkey, Uruguay, Brazil, Chile, Colombia, Israel, Ecuador, Australia, Mexico, Argentina, Tunisia, Belize, Canada, Cape Verde, Costa Rica, Cuba, Egypt, Kenya, New Caledonia, South Africa, Tanzania, Togo, United States, and Vietnam, in cities acting as replicators or followers of solutions developed in Europe (Urban Nature, 2024; Oppla, 2024). The differing contexts require adaptations of NbS: while European cities tend to focus on quality of life and climate resilience through BGI, regions in Latin America, Africa, and Asia apply NbS to address more urgent challenges, such as water management, flood reduction, and the restoration of degraded ecosystems.

The innovative contribution of this work lies in the systematization of NbS typologies, the analysis of methods and technologies or practices employed in the projects, and the identification of the main challenges to be addressed, thus providing an integrated perspective on current practices and future opportunities for promoting urban resilience and sustainability in a *lato sensu* sense.

The article is structured into four sections. Following this brief introduction, Section 2 describes the methods employed. Section 3

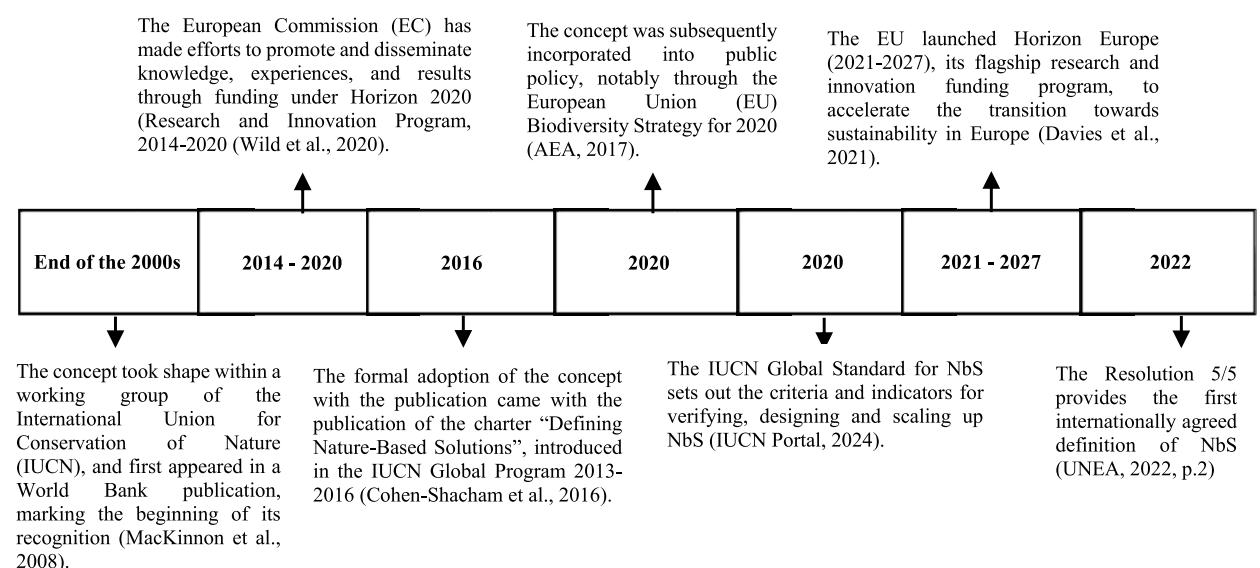


Fig. 1. Evolution of nature-based solutions since 2000.

Sources: Authors' own elaboration.

presents contributions on the concept and application of NbS in urban environments, as well as the main outcomes achieved, potential research areas, and discussion. We identify and present the most recent and relevant NbS projects implemented, considering aspects such as location, objectives and purposes, methods employed, and challenges faced. Finally, the article concludes by outlining the main findings and directions for future research.

2. Methodology

The methodology adopted in this study follows a multifaceted approach employing mixed methods that integrate both quantitative and qualitative elements, alongside the use of secondary sources. The methodological strategy was designed to achieve the research objectives, prioritizing the following sources. Quantitative methods involved a descriptive analysis of NbS projects, from which 66 were selected. Qualitative methods included content review and synthesis of project information, allowing for a more in-depth analysis of challenges and practices in climate change adaptation and urban resilience, among others.

An analysis of seven EU-funded research and development community information repositories was undertaken, that is, a review of NbS projects funded under EU programs. This was essential to contextualize relevant projects on NbS and the transition to sustainability particularly in urban environments. The analysis addresses the central question of this study, by focusing on the application of NbS and providing insights into a range of variables, such as their objectives and purposes, geographical scale, methodologies and technologies employed, expected environmental impacts, and challenges that contribute to adaptation and resilience to climate change.

This review provides evidence of effective strategies to mitigate the challenges faced by communities. Accordingly, a systematic review of EU-funded projects between 2014 and 2023 was conducted in line with the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Siddaway et al., 2019), in order to identify, evaluate, and synthesize information on key topics, with the aim of identifying pre principal issues related to NbS and, consequently, climate change.

The review was based on projects launched between 2014 and 2023 and retrieved from EU research and development repositories, including COST Action, Life 3.0, Interreg Europe, Interreg-Sudoe, Atlantic Area, POCTEP and CORDIS, by using the keyword "Nature-based Solutions" to identify relevant projects.

The study was carried out within the framework of a Portuguese project, ADMITUR – Promotion of Nature-Based Solutions for the Adaptation and Mitigation of the Tourism Sector to Climate Change, integrated into and funded by the Landscape, Heritage, and Territory Laboratory (Lab2PT). This involved consulting financial program databases related to the Portuguese territory, which motivated the analysis of the projects included in the databases listed in Table 1 and Fig. 2.

In addition to the Interreg programs listed in Table 1, the study also included projects funded through COST ACTION, Life 3.0 Europe, and the EU's project and results information source, CORDIS.

COST Actions typically involve researchers from academia, SMEs, public institutions, and other relevant stakeholders, covering all areas of science and technology, including emerging domains. COST actions provide an inclusive, pan-European environment enabling individuals at all career stages to develop their professional research networks. These initiatives are supported through EU funding programs such as Horizon Europe, the EU Framework Program for Research and Innovation. COST full members currently include: Albania, Armenia, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Moldova, Montenegro, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey,

Table 1
Characteristics of the Interreg programs used.

	POCTEP	Atlantic Area	Interreg-Sudoe	Interreg Europe
Cross-border cooperation (Scale)	Interreg A	Interreg B		Interreg C
Interreg Objective	Support cooperation between NUTS III regions from at least two Member States.	It brings together regions from different EU countries to foster strong cooperation and regional development.		Pan-European scale, creating networks to develop best practices and facilitate the exchange and transfer of experiences.
Total budget of Interreg	6.7 thousand million €.	2.3 thousand million €.		5.5 million €.
Total budget of the program	427 million € (largest cross-border cooperation program in the EU).	113 million €.	115.3 million €.	394 million €.
Program funding period (most recent)	2021–2027.			
Countries responsible for the program	Portugal and Spain.	Portugal, Spain, France, and Ireland.	Portugal, Spain, and France.	36 countries – the EU27 and Albania, Bosnia and Herzegovina, Moldova, Montenegro, North Macedonia, Norway, Serbia, Switzerland, and Ukraine.
Reference	POCTEP (2025)	(Atlantic Area, 2025)	Interreg-Sudoe (2025)	Interreg Europe (2025)

Source: Authors' own elaboration.

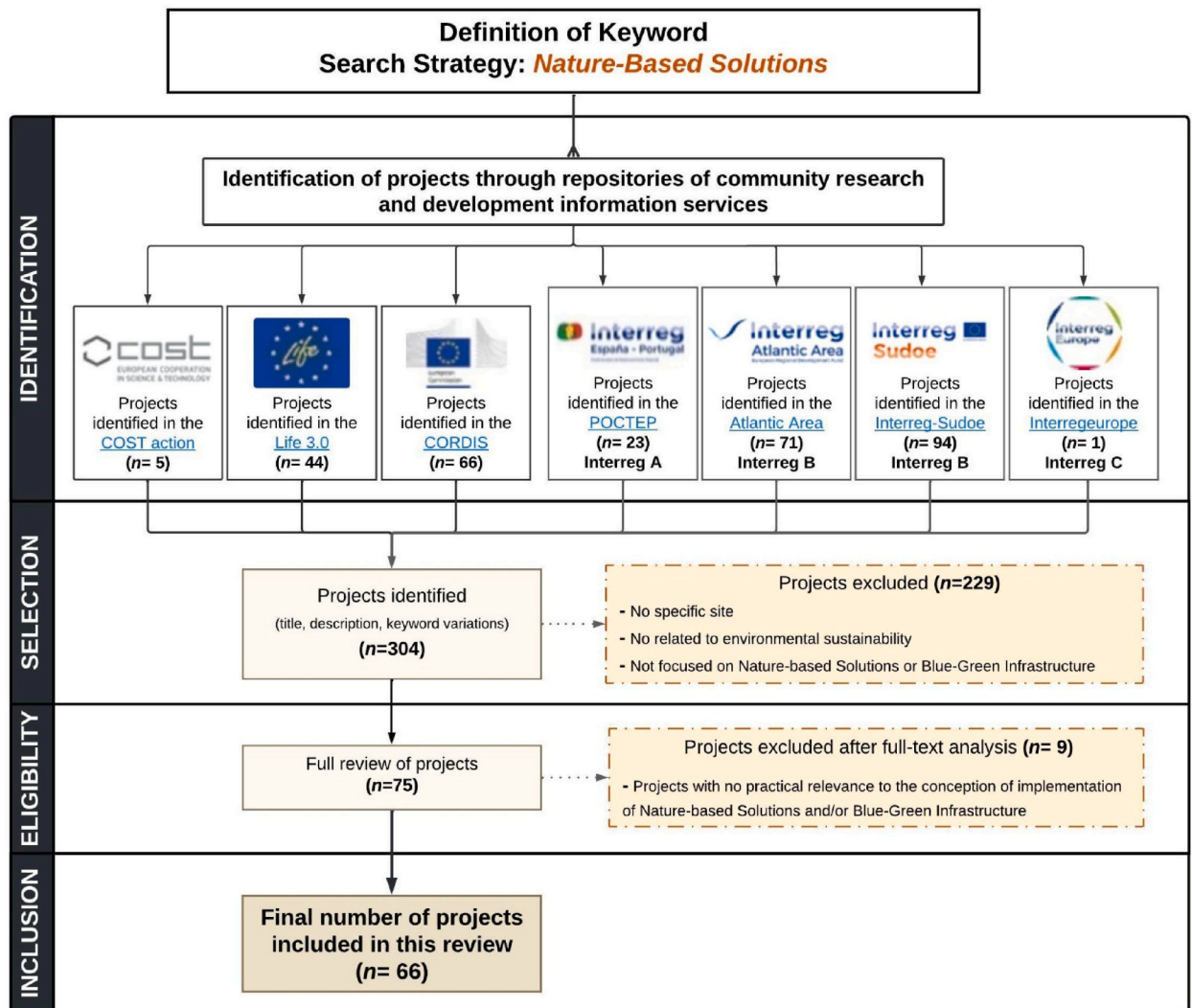


Fig. 2. Flowchart of the selection and review process of projects in the selected repositories.

Sources: Authors' own elaboration.

Ukraine and the United Kingdom. In addition, Israel is a cooperating member, and South Africa is a partner member.

The LIFE Program (2021–2027) is a financial instrument dedicated to the environment and climate action (Piwowarczyk and Jaś-Nowopolska, 2024). It aims to support the transition to a sustainable, circular, and energy-efficient economy, halt and reverse biodiversity loss, and combat ecosystem degradation. The total budget allocated to the LIFE Program for this period is EUR 5.4 million. LIFE is open to the participation of European Free Trade Association (EFTA) members, European Economic Area (EEA) members, accession countries, candidate and potential candidate countries, European Neighbourhood Policy countries, and other countries that agree to the terms and conditions established.

CORDIS provides a structured and publicly accessible repository of information on projects managed by the EC. Projects included in CORDIS are funded by various EU programs and initiatives, including Horizon 2020, and its successor, Horizon Europe. For example, Horizon 2020, the EU's primary research and innovation program for 2014–2020, had a total budget of around €80 billion. The subsequent program, Horizon Europe (2021–2027), boasts an even more substantial budget, amounting to approximately €95.5 billion (Tenhunen-Lunkka and Honkanen, 2024).

Using these databases, we conducted a search of records in the repositories of the community research and development information services listed in Fig. 2 from November 21, 2023 to January 4, 2024.

In the first phase, an inquiry was carried out based on access to the aforementioned community R&D information service repositories, resulting in the analysis of 304 EU-funded research projects supported by public funds. The selection of these repositories for the NbS search was based on a careful assessment of their thematic relevance and recognition for hosting a wide range of research and development projects related to the topic. Furthermore, they represent a variety of programs and institutions actively engaged in funding and supporting projects within the scope of our analysis.

In the present study, we chose to utilize the sources listed in Fig. 2 to identify NbS projects, rather than limiting ourselves to the EU Commission's list of NbS projects. This decision was taken to include a wider variety of projects employing NbS, including those funded through other sources, such as Interreg programs, Climate Action Plans, etc., which reference NbS directly or indirectly. From these repositories, projects were identified using the keyword "Nature-based Solutions". This approach avoids restricting our analysis to the 76 NbS research projects funded by the EC as of December 7, 2024, allowing for a more comprehensive overview that better reflects the diversity and practical application of NbS across different contexts.

The second step involved evaluating the contribution of these projects to the advancement of scientific knowledge on key policies and interventions related to urbanization, with a view to developing more resilient and environmentally sustainable cities. Of the initial 304 research projects, 229 were excluded as they were not directly related to the primary objective of investigating the importance of NbS, particularly in relation to BGI, and were not urban or peri-urban in scope or did not serve the purpose of the research.

The exclusion criterion ensured that the analysis focused exclusively on recent projects (with starting dates between 2014 and 2023) that address the relevance and impact of NbS in the urban BGI context, thereby enabling the assessment of techniques and practices, recent developments and innovative approaches. However, some projects included in the review extend beyond the territorial limits of urban and peri-urban areas (Table 3), due to their significant relevance to these environments, either through direct impact or management.

In the third phase, following the identification of relevant projects, the selection process involved a comprehensive project analysis, with nine projects being excluded for not fully addressing the study's objective.

Given the innovative nature of the NbS concept, no single method exists for identifying and classifying related projects. In this study, we aimed to analyse not only projects categorized as NbS by the EC (Table 3) but also those aimed at climate change adaptation and mitigation, such as Climate Action Plans, employing NbS to demonstrate the multifaceted nature of these initiatives. These actions have the potential to significantly contribute to achieving net zero CO₂ emissions and decarbonization, while mitigating risks associated with nature loss, biodiversity decline and ecosystem collapse. Nevertheless, we adapted specific criteria to assess the quality and relevance of each project. As a result, 66 projects were retained for inclusion and were analysed for the variables listed in Table 2.

The study demonstrates a strong alignment with the social challenges identified in the IUCN Global Standard, clearly addressing critical issues such as climate change adaptation, water security, health and well-being, biodiversity restoration, and inclusive governance (IUCN, 2020). The reviewed NbS projects are presented as integrated solutions to urban challenges, promoting both climate and social resilience. Moreover, the focus on verifying processes of social inclusion and participatory governance reflects the IUCN's emphasis on reducing inequalities and engaging local communities. Consideration of economic benefits, such as resource use-efficiency, further underscores the relevance of NbS in building economic and environmental resilience in urban areas. The

Table 2
Typologies used in different variables.

Purpose and objectives	Typology	Methodology	Technologies and practices	Expected impacts	Community involvement	Urban and Peri-urban Challenges
Adaptation of water resources	BGI or ecosystem creation	Awareness activities and knowledge exchange	Circular economy practices	Climate and ecological adaptation and resilience	Business community	Behaviour changes and community involvement
Adaptation to extreme heat events	Conservation practices for existing ecosystems	Circular economy and resource management practices.	Governance and management practices	Improvement of living and sound conditions, social inclusion and well-being	Citizens	Cooperation and coordination between territorial units
Climate adaptation and focus on promoting biodiversity	Restoration of degraded ecosystems	Environmental monitoring, modelling, and scenario simulation	Green technologies and ecological engineering solutions	Improvement of public health conditions	Civil society/ NGO	Financing and access to decision-making instruments
Communication or awareness		Governance and information sharing across territories	Green infrastructure systems	Preservation of cultural heritage	Government entities	Implementation and replication of efficient solutions.
Economic stimulus		Planning and participatory co design	Monitoring technologies and climate risk management	Promotion of biodiversity and habitats	Scientific community	
Smart cities		Risk management and climate adaptation		Promotion of circular economy practices	Schools	
Soil sustainability		Strategies for implementing BGI		Promotion of water quality and availability Reduction of pollutant gases and improvement of air quality		

Source: Authors' own elaboration.

Table 3

Nature-based Solutions projects considered by the European Commission included in the review.

Project title included	Project NbS	Category
Nature-based Solutions in urban and peri-urban areas		
Coproduction with nature for city transitioning, innovation and governance (European Commission, 2025a)	<i>Connecting Nature</i>	Climate resilience
Green cities for climate and water resilience, sustainable economic growth, healthy citizens and environments (European Commission, 2025b)	<i>Grow Green</i>	Climate resilience
New strategy for re-naturing cities through Nature-based Solutions (European Commission, 2025c)	<i>URBAN GreenUP</i>	Climate resilience
Urban nature labs (European Commission, 2025d)	<i>UNaLab</i>	Climate resilience
Innovative and enhanced Nature-based Solutions for sustainable urban water cycle (European Commission, 2025e)	<i>NICE</i>	Water security
Clever cities - Co-designing locally tailored ecological solutions for value added, socially inclusive regeneration in cities (European Commission, 2025f)	<i>CLEVER Cities</i>	Inclusive urban regeneration
Nature-based urban innovation (European Commission, 2025g)	<i>NATURVATION</i>	Inclusive urban regeneration
Nature-based Solutions for re-naturing cities: knowledge diffusion and decision support platform through new collaborative models (European Commission, 2025h)	<i>Nature4Cities</i>	Inclusive urban regeneration
Productive green infrastructure for post-industrial urban regeneration (European Commission, 2025i)	<i>ProGReg</i>	Inclusive urban regeneration
Urbanat - Healthy corridors as drivers of social housing neighbourhoods for the co-creation of social, environmental and marketable NbS (European Commission, 2025j)	<i>URBINAT</i>	Inclusive urban regeneration
Edible cities network integrating edible city solutions for social resilient and sustainably productive cities (European Commission, 2025k)	<i>EdiCiNet</i>	Inclusive urban regeneration
Clearing house - Collaborative learning in research, information-sharing and governance on how urban tree-based solutions support Sino-European urban futures (European Commission, 2025l)	<i>CLEARING HOUSE</i>	Nature protection and restoration
Fostering Nature-based Solutions for smart, green and healthy urban transitions in Europe and China (European Commission, 2025m)	<i>REGREEN</i>	Nature protection and restoration
Co-producing Nature-based Solutions and restored ecosystems: transdisciplinary nexus for urban sustainability (European Commission, 2025n)	<i>CONEXUS</i>	Nature protection and restoration
International cooperation to restore and connect urban environments in Latin America and Europe (European Commission, 2025o)	<i>INTERLACE</i>	Nature protection and restoration
Integrated NbS-based urban planning methodology for enhancing the health and well-being of citizens: the Eupolis Approach (European Commission, 2025p)	<i>EUPOLIS</i>	Health and wellbeing
Go Green: Resilient optimal urban natural, technological and environmental solutions (European Commission, 2025q)	<i>GO GREEN ROUTES</i>	Health and wellbeing
Visionary nature-based actions for health, wellbeing & resilience in cities (European Commission, 2025r)	<i>VARCITIES</i>	Health and wellbeing
The power of diversity and social inclusion as a mean for reducing air pollution and achieving green urban nexus in climate neutral cities (European Commission, 2025s)	<i>DivAirCity</i>	Air quality
Activation of Nature-based Solutions for a just low carbon transition (European Commission, 2025t)	<i>JUSTNature</i>	Air quality
City-centered approach to catalyse Nature-based Solutions through the EU regenerative urban lighthouse for pollution alleviation and regenerative development (European Commission, 2025u)	<i>UPSURGE</i>	Air quality
Cross-cutting projects		
Nature insurance value: Assessment and demonstration (European Commission, 2025v)	<i>NAIAD</i>	Nature positive economy, finance and insurance
NetworkNature - Advancing Nature-based Solutions together (European Commission, 2025w)	Networknature+ (Platform)	
Consolidating the European research area on biodiversity and ecosystem services (European Commission, 2025x)	European biodiversity partnership BIODIVERSA+	
Nature-based Solutions beyond urban and peri-urban areas		
Pond ecosystems for resilient future landscapes in a changing climate (European Commission, 2025y)	<i>PONDERFUL</i>	Climate resilience
Climate change and future marine ecosystem services and biodiversity (European Commission, 2025z)	<i>FutureMARES</i>	Climate resilience
Open-air laboratories for Nature-based Solutions to manage hydro-meteo risks (European Commission, 2025aa)	<i>OPERANDUM</i>	Climate resilience
Phusicos: 'According to nature' - solutions to reduce risk in mountain landscapes (European Commission, 2025ab)	<i>PHUSICOS</i>	Climate resilience
Mainstreaming ecological restoration of freshwater-related ecosystems in a landscape context: innovation, upscaling and transformation (European Commission, 2025ac)	<i>MERLIN</i>	Nature protection and restoration
Marine ecosystem restoration in changing European seas (European Commission, 2025ad)	<i>MERCES</i>	Nature protection and restoration

Source: Authors' own elaboration.

analysed projects are categorized according to objectives such as climate resilience and urban health, illustrating a robust typology capturing the multifunctionality of NbS. The study emphasizes the importance of participatory and integrated processes to ensure that solutions are locally adapted and socially accepted. Additionally, the analysis incorporates mechanisms for continuous monitoring to evaluate the effectiveness of NbS, aligning with the IUCN classifications for efficient implementation.

3. Results and discussion

3.1. Spatial distribution by country and cities

In this study, was conducted a detailed review of the projects included, focusing on sustainability-oriented interventions within programmes submitted/approved between 2014 and 2023, with completion dates ranging from 2018 to 2029. This approach allows for the analysis of cases across different European localities and includes projects implemented outside the European continent through partnerships. Therefore, this study is enriched by the consideration of the diversity of territorial, cultural, political, and socio-economic contexts. Which confirms that NbS are increasingly regarded as a global tool, whose scope extends beyond the EU, reflecting the growing internationalisation of these practices, with the EU as their driving force through its global reach and leadership in ecological sustainability projects, and by seeking to channel this leadership to demonstrate, once again, its role as a forerunner of good environmental practices through the use of NbS (Faivre et al., 2017; de Luca et al., 2021).

Subsequently, the geographical distribution (by country and city) of the institutions responsible for each project was determined (Fig. 3). The 66 projects analysed were hosted by institutions located in 20 countries, covering a total of 62 cities.

The most representative country was Spain ($n = 15$), with research conducted in 12 cities, followed by Italy ($n = 7$), with research in 6 cities. The most representative cities were Barcelona ($n = 2$) (Fundacion Privada Instituto De Salud Global Barcelona, and Universidad Pompeu Fabra), Seville ($n = 2$) (Agencia de Régimen Especial del Ciclo Integral de las Aguas del Retortillo, and Agencia Andaluza de la Energía), and Valladolid ($n = 2$) (Foundational Santa María la Real del Patrimonio Historic, and Confederación Hidrográfica del Duero) in Spain and Milan ($n = 2$) (Istituto Oikos, and Città Metropolitana di Milano) in Italy.

A higher concentration is observed in southern European countries, such as Spain, Italy, and Portugal, in a contrast with a lower presence in eastern and northern European countries (Fig. 3). This discrepancy can be partially explained by economic and institutional factors. It has been demonstrated that regions with superior access to European funding and higher administrative capacity, such as Northern Italy or the metropolitan areas of Spain, France, and Portugal, exhibit a higher density of projects. Conversely, rural areas or less developed regions, such as southern Italy, the interior of Portugal, or countries in Eastern Europe, tend to be underrepresented. This phenomenon reflects inequalities in investment and the technical capacities of research units or institutions engaged in spatial

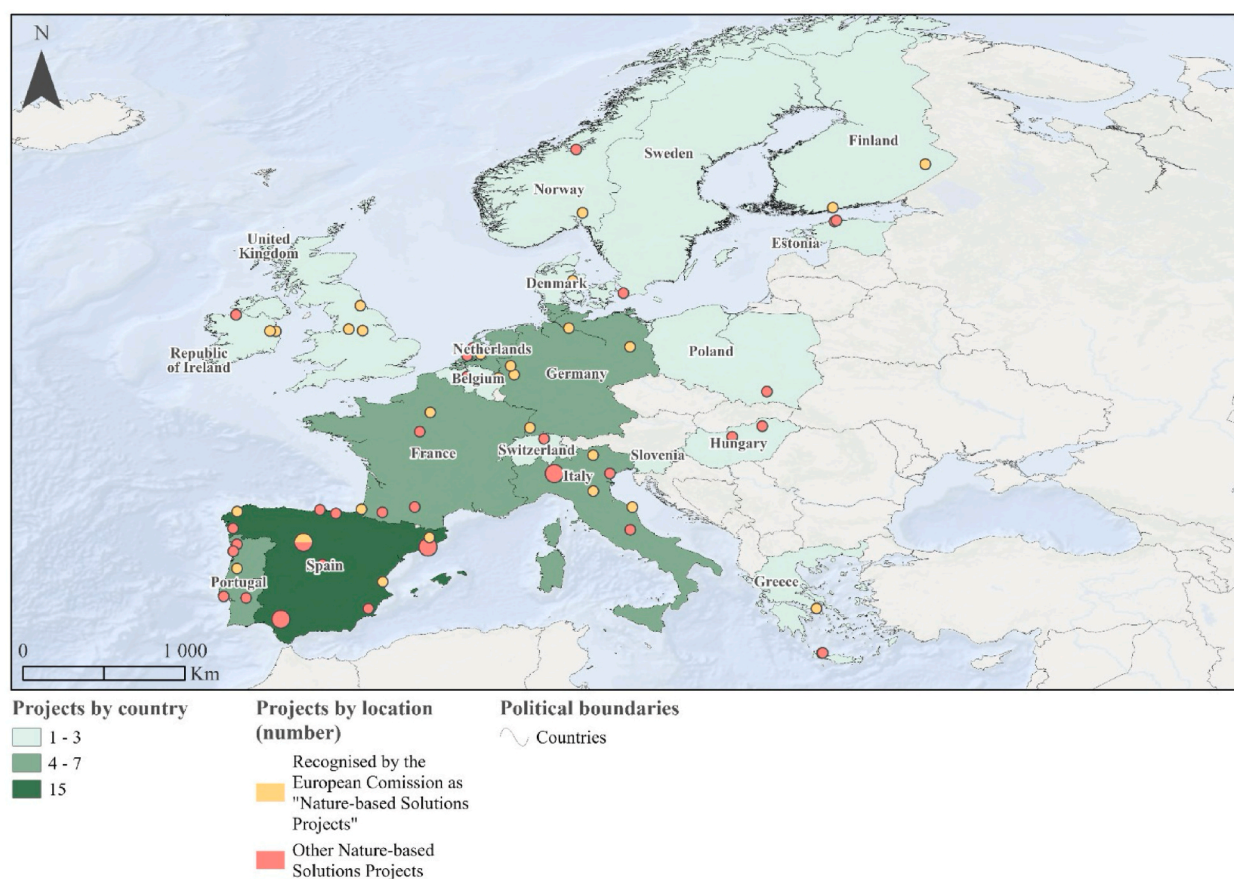


Fig. 3. Spatial distribution by countries and cities of the institutions responsible for the projects analysed.

Sources: Authors' own elaboration.

planning and territorial governance (Faivre et al., 2017; Wild et al., 2020; Banzhaf et al., 2022). These differences suggest that the implementation of NbS and projects aimed at ecological sustainability, climate adaptation, and resilience is conditioned not only by environmental factors but also by economic dynamic and territorial governance (Kotsila et al., 2021; Torre, 2025).

3.2. Scale and scope of application of projects

From the perspective of assessing where good practices in climate adaptation and resilience, biodiversity promotion, and ecosystem services are being implemented and adopted, it is essential to understand the geographic distribution of the study areas and the application of measures or preliminary studies related to the benefits of NbS for population well-being and the local environment.

Fig. 4 presents the location of exploratory cases and experimental applications of NbS, with points proportional to the scale of analysis, covering cities and other urban and peri-urban areas (districts or neighbourhoods) that promote the use of NbS within the built environment. Across the 66 projects analysed, applications were identified in 365 territorial units distributed across 63 countries. The territorial breadth indicates the consolidation of NbS as a cross-cutting strategy and as a means of responding to environmental challenges at multiple scales, ranging from the intra-urban to the European level. This finding aligns with the conclusions of the study by De Lotto et al. (2021).

Some projects operate at national scales, while others cover the European scale, consequently, in certain cases, Fig. 4 does not associate specific territorial entities, particularly where the work is conducted at meso-and macro scales. Most initiatives involve partnerships between countries, regions, or cities, according to the geographical scale of NbS implementation. The configuration of multi-level partnerships suggests that the implementation of nature-based solutions (NbS) is contingent on collaboration and the exchange of best practices and knowledge between territories. This collaborative environment has the potential to enhance the

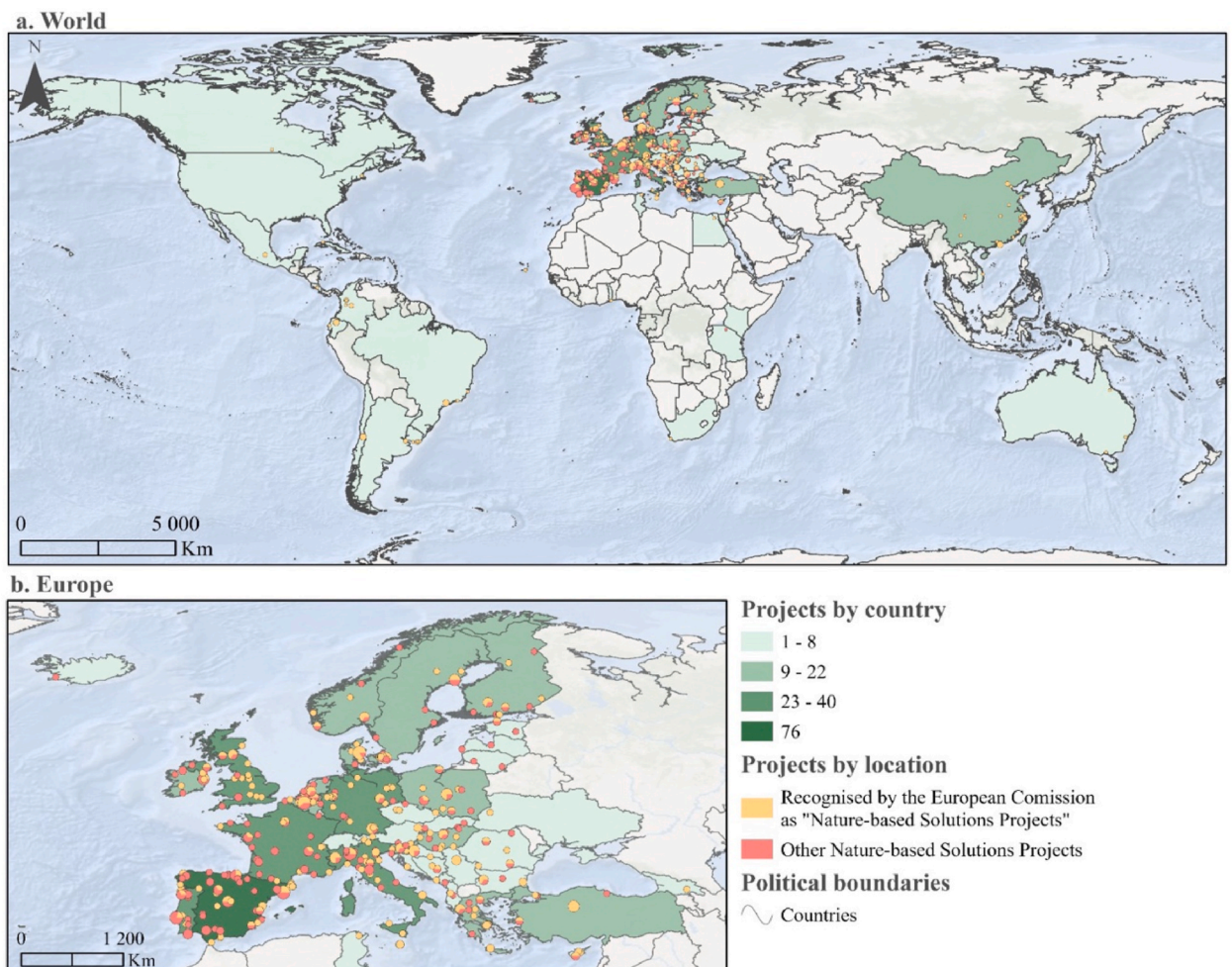


Fig. 4. Spatial distribution by country and city where the Nature-based Solutions projects were included in the review were implemented, worldwide (a.) and in Europe (b.).

Sources: Authors' own elaboration.

replicability and transferability of NbS practices, thereby expanding their impact and application (Castelo et al., 2023). The countries with the highest representation are Spain ($n = 76$), Italy ($n = 40$), France ($n = 36$), Germany ($n = 29$), and Portugal ($n = 28$).

The considerable presence of Spain, Italy, and France verifies the prominence of these nations in establishing urban sustainability policies. This phenomenon may be associated with their substantial investment in LIFE programs and urban regeneration through biophilic design, consistent with recent literature on environmental investment in southern European countries (Hurtado, 2017; Ferreira et al., 2023). This indicator underscores the dedication of these nations to the transition toward sustainability and emphasizes the significance of the European funds examined (see section 2) in supporting and promoting adaptive and resilient actions across

Table 4

European Union funded projects that look beyond Europe.

Project Acronyms	European Countries	Non-European Countries	Total coast and EU funding share (%)
NetZeroCities (European Commission, 2025ae)	Albania, Austria, Belgium, Bulgaria, Bosnia and Herzegovina, Czech Republic, Cyprus, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Iceland, Letonia, Lithuania, Luxembourg, Malta, Montenegro, Netherlands, Norway, Portugal, Poland, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom	Israel and Turkey	€52 996 604.88 (100 %)
BiodivERsA3 (European Commission, 2025x)	Austria, Belgium, Bulgaria, Estonia, Finland, France, Germany, Hungary, Ireland, Lithuania, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland, and United Kingdom	Israel, New Caledonia (dozens of islands in the south Pacific Ocean) and Turkey	€38 974 332.66 (33 %)
MERLIN (European Commission, 2025a)	Austria, Belgium, Bosnia and Herzegovina, Croatia, Denmark, Finland, Germany, Hungary, Netherlands, Poland, Portugal, Romania, Spain, Sweden, and United Kingdom.	Israel	€22 103 209.32 (96.1 %)
CLEVER Cities (European Commission, 2025f)	Germany, Greece, Italy, Romania, Serbia, Spain, Sweden, and United Kingdom	Ecuador	€14 864 688.84 (95.6 %)
URBAN GreenUP (European Commission, 2025c)	Czech Republic, Cyprus, Denmark, Finland, Germany, Greece, Hungary, Italy, Portugal, Spain, Sweden, United Kingdom, and Ukraine	Brazil, Cape Verde, Chile, China, Colombia, Tunisia, Turkey and Vietnam	€14 802 476.25 (94.4 %)
OPERANDUM (European Commission, 2025a)	Austria, Finland, Germany, Greece, Ireland, Italy, and the United Kingdom	Australia and China	€14 696 501.68 (83.4 %)
UNALAB (European Commission, 2025d)	Czech Republic, Finland, France, Italy, Netherlands, Norway, and Spain	Argentina and China	€14 278 699.25 (89.4 %)
EdiCitNet (European Commission, 2025k)	Germany, Netherlands, Norway, Slovenia, and Spain	China, Cuba, Togo, Tunisia, Uruguay	€11 763 163.52 (95.7 %)
ProGleg (European Commission, 2025i)	Bosnia and Herzegovina, Croatia, Germany, Greece, Italy, Portugal, Romania	China	€11 633 268.87 (89.7 %)
GROW GREEN (European Commission, 2025b)	Croatia, France, Italy, Poland, Spain, and United Kingdom	China	€11 514 817.76 (97.5 %)
EuPOLIS (European Commission, 2025p)	Bosnia and Herzegovina, Cyprus, Denmark, Greece, Italy, Poland, and Serbia	Colombia	€11 358 637.39 (88 %)
GO GREEN ROUTES (European Commission, 2025q)	Austria, Belgium, Bulgaria, Denmark, Estonia, Finland, France, Georgia, Germany, Ireland, Italy, Malta, Netherlands, Norway, Spain, Sweden, and United Kingdom	China and Mexico	€11 148 168.12 (94.1 %)
SCORE (European Commission, 2025af)	Ireland, Italy, Poland, Portugal, Slovenia, and Spain	Turkey	€9 980 831.00 (100 %)
AfricanBioServices (European Commission, 2025ag)		Kenya and Tanzania	€9 891 768.50 (100 %)
FutureMARES (European Commission, 2025z)	Denmark, Finland, France, Germany, Greece, Italy, Netherlands, Norway, Portugal, Spain, Sweden, and United Kingdom	Belize, Chile, and Israel	€8 555 905.00 (100 %)
NATURVATION (European Commission, 2025g)	Bulgaria, France, Germany, Greece, Hungary, Ireland, Netherlands, Spain, Sweden, and United Kingdom	Australia, Canada, China, Mexico, South Africa, and United States	€7 797 877.50 (100 %)
CLEARING HOUSE (European Commission, 2025l)	Austria, Belgium, Croatia, Denmark, Finland, France, Germany, Italy, Poland, Slovenia, Spain, and United Kingdom	China	€7 687 863.75 (64.9 %)
Nature4Cities (European Commission, 2025h)	Hungary, Italy, and Spain	Turkey	€7 499 981.25 (100 %)
PONDERFUL (European Commission, 2025y)	Germany, Belgium, Denmark, Spain, United Kingdom, and Switzerland	Turkey and Uruguay	€6 993 407.50 (100 %)
CONEXUS (European Commission, 2025n)	Germany, Italy, Portugal Spain, Sweden, and United Kingdom	Argentina, Brazil, Chile, Colombia, Ecuador and Mexico	€5 635 956.25 (88.7 %)
INTERLACE (European Commission, 2025o)	Germany, Polonia, Spain	Colombia, Costa Rica and Ecuador	€5 476 165.00 (100 %)
REGREEN (European Commission, 2025m)	Croatia, Denmark, France	China	€5 325 013.84 (93.8 %)
NICE (European Commission, 2025e)	Albania, Austria, Czech Republic, Denmark, France, Italy, Poland, Serbia and Spain	China, Colombia, Ecuador, and Egypt	€4 996 342.00 (100 %)
Niche4NbS (European Commission, 2025ah)		Israel	€1 500 000.00 (100 %)

Sources: Authors' own elaboration.

various geographical areas (Faivre et al., 2017; Frantzeskaki, 2019). Despite the considerable implementation of projects in Spain, Italy, France, Germany, and Portugal, Italy and Portugal did not manage any EU-funded projects with funding exceeding 90 %. This is particularly noteworthy when considering EU-funded projects implemented beyond the European continent's territorial limits (Table 4). Of the 18 projects with EU funding above 90 %, Germany stands out as the most prominent, securing five projects (including one fully funded); followed by Spain with three projects (two fully funded), the Netherlands with two projects (both fully funded), and Ireland and the United Kingdom with two projects each (one of which in each country receiving full funding).

Beyond European borders, several countries and cities benefit from these good practices in partnership with the EU (Oppla, 2024). Notable cases include (22 projects), Turkey (10), Uruguay (6), Brazil, Chile and Colombia (5 each), Ecuador (4), Australia and Mexico (3 each), Argentina and Tunisia (2 each), and, with one project each Belize, Canada, Cape Verde, Costa Rica, Cuba, Egypt, Kenya, New Caledonia (a group of islands in the southern Pacific Ocean), South Africa, Tanzania, Togo, United States and Vietnam (Figs. 4 and 5).

It is important to highlight that all projects, with the exception of two – *Niche4NbS* (Israel only) and *AfricanBioServices* (Kenya and Tanzania only) – among those involving countries outside Europe geographical boundaries ($n = 24$) are conducted in partnership with European countries and/or cities (Table 4). The review of EU-funded projects demonstrates that, although NbS are strongly represented in Mediterranean and Atlantic countries, their implementation is also expanding beyond European through partnerships (O'Sullivan et al., 2020), as mentioned, underscoring their strategic importance in distinct climatic and socio-economic contexts.

The analysis of EU-funded projects that are also implemented beyond the territorial boundaries of the European continent (listed in Tables 4 and 5) indicates four patterns in the application of NbS. The most prevalent NbS are grouped into four main categories: i) urban green infrastructure (green roofs and walls, ecological corridors, and urban parks), evident in initiatives such as *URBAN GreenUP*, *CLEVER Cities*, *proGleg*, *GROW GREEN*, *NetZeroCities*, *REGREEN*, and *GO GREEN ROUTES*; ii) river and wetland restoration, applied in projects such as *MERLIN*, *OPERANDUM*, *PONDERFUL*, *INTERLACE*, and *CONEXUS*; iii) solutions aimed at improving urban climate comfort, including the creation of cooling islands and multifunctional spaces, highlighted in *CLEVER Cities*, *URBAN GreenUP*, *COOLCITY*, and *GO GREEN ROUTES*; and iv) socially driven approaches, namely living labs and co-design processes, which feature strongly in *CLEVER Cities*, *UNALAB*, *SCORE*, *proGleg*, *EdiCitNet*, and *DivAirCity* (Table 5). It is evident that most of the NbS implemented continue to be based on classical ecological support measures (green infrastructure and water restoration), complemented by mechanisms of social innovation (co-governance and community participation).

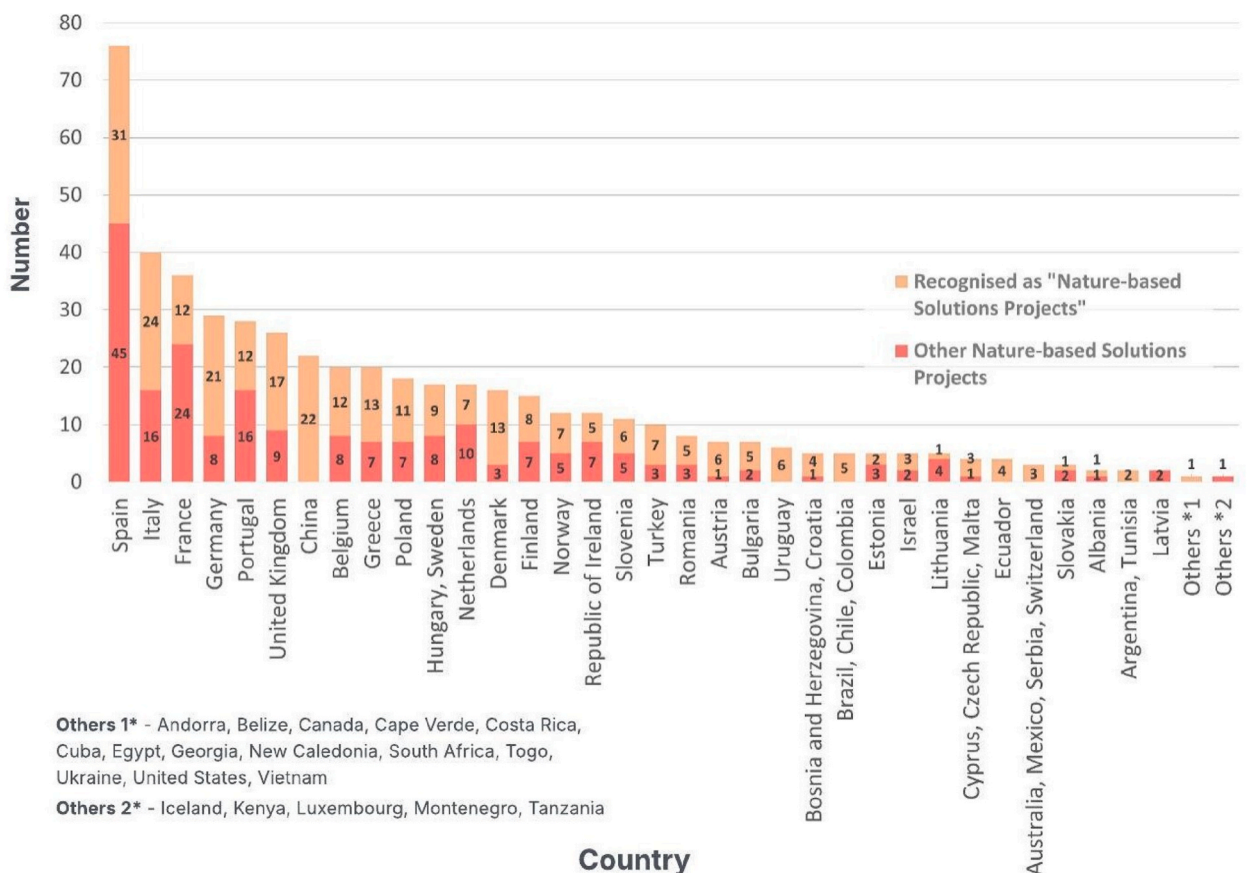


Fig. 5. Distribution of Nature-based Solutions projects included in the review by country.

Sources: Authors' own elaboration.

Table 5

Nature-based solutions used in EU-funded projects that look beyond Europe.

Project Acronyms	NbS employed	Scale of application
NetZeroCities (European Commission, 2025a)	Urban gardens, modular green roofs/walls with smart irrigation, urban renaturalisation, urban soil carbon capture.	Urban/peri-urban
BiodivERS43 (European Commission, 2025x)	Conservation of ecosystems, ecological corridors and pollinators, ecological restoration, adaptive management of urban forests, and revegetation of urban slopes.	National/transnational
MERLIN (European Commission, 2025a)	Restoration of rivers, wetlands, recreation of floodplains and natural banks, natural ponds.	Fluvial/peri-urban
CLEVER Cities (European Commission, 2025f)	Green roofs and walls with greywater irrigation, urban parks, ecological transport corridors.	Urban
URBAN GreenUP (European Commission, 2025c)	Rain gardens, green corridors, renaturalisation of riverbanks, biofiltration parks, multifunctional retention basins, renaturalisation of urban channels.	Urban/fluvial
OPERANDUM (European Commission, 2025a)	Artificial dunes reinforced with vegetation “living barriers, wetlands and vegetated buffers.	Coastal/fluvial
UNALAB (European Commission, 2025d)	Artificial wetlands in peripheral neighbourhoods, modular green roofs for public buildings, ecological corridors, sustainable water management with natural drainage systems for peak rainfall.	Urban/peri-urban
EdiCitNet (European Commission, 2025k)	Urban agriculture, such as community educational gardens, urban aquaponic gardens, and edible rooftops.	Urban/community-based
proGReg (European Commission, 2025i)	Biochar in degraded urban soils, urban agriculture in “empty” areas such as former industrial sites, rain gardens and filters.	Urban/peri-urban
GROW GREEN (European Commission, 2025b)	“Sponge cities”, urban parks, green corridors, natural drainage and underground reservoirs connected to green areas.	Urban
EuPOLIS (European Commission, 2025p)	Wetlands for water purification, retention basins, urban green spaces for health, and green corridors.	Urban/peri-urban
GO GREEN ROUTES (European Commission, 2025q)	Green corridors, “greenways” with cycling paths, regeneration of public spaces, therapeutic and sensory gardens, and accessible urban forests.	Urban/peri-urban
SCORE (European Commission, 2025a)	Restoration of dunes, reefs with native vegetation, coastal wetlands.	Coastal/marine
AfricanBioServices (European Commission, 2025a)	Conservation of savannahs for livestock and biodiversity, animal migration ecological corridors.	Natural
FutureMARES (European Commission, 2025z)	Seagrass meadows with seagrass restoration, artificial reefs with limestone structures.	Marine/coastal
NATURVATION (European Commission, 2025g)	Solutions cataloguing, including an inventory of resilient urban parks, maps of active green roofs.	Urban
CLEARING HOUSE (European Commission, 2025l)	Linear urban forests for ventilation corridors, urban tree planting, urban forestry using tree species adopted to urban heat.	Urban/peri-urban
Nature4Cities (European Commission, 2025h)	Interactive Nature-based Solutions catalogue, including examples such as urban bioswales, vegetated noise barriers.	Urban/peri-urban
PONDERFUL (European Commission, 2025y)	Conservation and restoration of agricultural ponds, creation of biodiversity ponds, and integration of wetlands with sustainable agriculture.	Peri-urban
CONEXUS (European Commission, 2025n)	Green corridors, ecological regeneration, and community green squares.	Urban
INTERLACE (European Commission, 2025o)	Restoration and renaturalisation of urban rivers, restoration of degraded peri-urban forests.	Urban/fluvial
REGREEN (European Commission, 2025m)	Urban forests, vegetation barriers against air pollution and urban noise, and green parks.	Urban/peri-urban
NICE (European Commission, 2025e)	Modular wetlands for wastewater treatment, natural bioretention and integration with urban biofilters.	Urban/peri-urban
Niche4NbS (European Commission, 2025a)	Scholl gardens, small-scale experimental green roofs, local stormwater retention wetlands.	Local/community-based

Sources: Authors’ own elaboration.

Concomitant with conventional NbS, the EU endorses mixed solutions that integrate nature with technological innovation, thereby expanding the range of interventions. Beyond conventional approaches, a distinct set of more innovative and technology-oriented NbS is also evident. Projects such as *MERLIN* and *OPERANDUM* employ hybrid solutions in natural environments, integrating ecological restoration with digital modeling and testing in “open-air laboratories”. The *FutureMARES* project is focused on the advancement of hybrid reefs and experimental marine solutions, while *proGReg* introduces the use of biochar in urban soils and water biofilters. The *NICE* project is distinguished by its incorporation of decentralized wetlands and green bioreactors, while *SCORE* integrates coastal monitoring with Internet of Things (IoT) sensors, drones, and community engagement. *UNALAB* and *CLEVER Cities* have also developed smart tools for monitoring the impacts of NbS.

The results allow the identification of three levels of technological maturity in the NbS analysed: i) traditional NbS, such as green roofs and ecological corridors, widely replicated across European cities; ii) advanced urban NbS, which embed social and institutional innovation through living labs and co-design processes; and iii) experimental NbS, which integrate high-risk scientific and technological innovation, but with significant potential for future replication. Evolution from solutions focused solely on urban ecology to hybrid approaches that interconnect technology, governance, and social participation.

From a territorial perspective, southern Europe concentrates interventions addressing adaptation to extreme heat and water

scarcity (e.g., Almada, Milan, Barcelona), while northern and western Europe are distinguished by the adoption of advanced technological solutions, such as digital monitoring systems (Netherlands, Germany, Denmark, Norway). As Ribeiro et al. (2025a) have demonstrated, the NbS, while sharing common objectives, are shaped by geographical, socioeconomic, and political contexts. This phenomenon is explained within the framework of sustainability transitions and the place-scale-space perspective.

3.3. Purpose and objectives of the projects

Based on a comprehensive review of the projects, a multidimensional framework is developed to categorise them, resulting in different typologies (Table 2). Given the specific interest in the application of NbS to benefit urban environments, categorisations are selected according to their utility and benefits, including contributions to urban planning and economic stimulation, relevance for environmental sustainability, and effectiveness in mitigation climate change (Table 6).

The main category comprises 25 projects (38 %), in which the central focus is climate adaptation and biodiversity promotion. These projects aim to adapt territories to multiple adversities (water or heat related extremes) and the foster biodiversity in the intervention areas (*LIFE PollinAction*, *LIFE-GREEN4GREY*, and *GREENTOUR*).

This is followed by 17 projects (26 %), focused on water resources, addressing coastal erosion, coastal and pluvial flooding, and limited water availability/quality (*LIFE22-CCA-NL-LIFE WATERSOURCE*, *LIFE22-CCA-SE-LIFECAPeable*, and *MERLIN*).

The categories of Smart Cities and Adaptation to extreme heat events include, respectively, 8 projects (12 %) and 7 projects (11 %). In the first, projects explicitly adopt smart city models, linking physical and mental well-being with zero pollutant emissions (*LIFE21-CCA-PL-LIFECOOLCITY*, *JUSTNature*, and *DivAirCity*). In the second, projects address heat islands, droughts, and an increase in consecutive days with high temperatures and low humidity, with impacts on the most vulnerable groups (*LIFE22-CCA-PT-COOL-IFEALMADA*, *LIFE-IP URBAN KLIMA, 2050*; and *Life + A_GreeNet*).

Considering the categories defined according to project objectives (Table 6), the analysis focuses on four main categories: i) climate adaptation with emphasis on biodiversity; ii) water resource adaptation; iii) transition towards smart cities with a focus on decarbonization; and iv) adaptation to extreme heat. Projects implemented outside the Europe are excluded from the analysis, except for Israel, due to their limited number and high dispersion, which prevents robust conclusions about their distribution.

The preponderance of initiatives concerning biodiversity and water resources underscores the prioritization by policymakers of the most pressing environmental concerns, namely climate change, water scarcity, and ecological degradation. This may suggest a monumental attempt at “makeshift problem-solving” rather than broad-spectrum planning, which would imply the anticipation of a problem or challenge (King et al., 2016). The integration of emerging categories, such as smart cities and adaptation to extreme heat, exemplifies the endeavor to align NbS with urban innovation, public health, and energy transition agendas, in accordance with the Sustainable Development Goals (SDGs) 11 – Sustainable Cities and Communities, 13 – Climate Action, and 15 – Life and Land (Tarantino, 2024; Sharma et al., 2025; Zhao et al., 2025). This diversity of objectives confirms that NbS are conceived as multi-functional solutions, capable of delivering environmental, social, and economic co-benefits (Ferreira et al., 2023).

The spatial distribution of the four categories reveals distinct patterns (Fig. 6). The categories identified – climate adaptation and focus on promoting biodiversity ($n = 25$), adaptation to water resources ($n = 17$), transition to smart cities ($n = 8$) and adaptation to extreme heat ($n = 7$) reflects the urgency of the challenges facing the world and Europe. The concerns with the promotion, conservation, and restoration of biodiversity as a pillar of resilience to climate change, scarcity of water resources, the need to reduce carbon emissions in urban and peri-urban areas, and the increasing impacts of extreme heat make these categories a priority for the adoption of nature-based interventions.

The spatial distribution of the four categories presents distinct patterns (Fig. 6). For projects with a focus on biodiversity for climate adaptation (Fig. 6a), there is a recognition of the interdependence between natural systems and human needs, acknowledging biodiversity as a pillar of resilience. These projects are found both in densely populated areas and in natural regions where the original ecosystem has been disrupted. Water resources projects and those related to biodiversity and climate adaptation are spread widely across the continent (Fig. 6b). Smart city projects are concentrated in densely populated urban and peri-urban areas (Fig. 6c); while extreme heat projects occur more frequently in southern Europe (Fig. 6d), reflecting harsher climatic conditions, projected aggravations, and pressures in large population centres. In summary, the spatial variation aligns with the nature of local challenges: the

Table 6
Projects divided into categories according to their purpose.

Purpose and Objectives	Number		Relevant Literature
	(N°)	(%)	
Climate adaptation and focus on promoting biodiversity	25	38	(Roche and Campagne, 2017; Arlati et al., 2021; Croeser et al., 2021; Phillips et al., 2023).
Adaptation of water resources	17	26	(Velasco et al., 2018; Coll, 2021; Danovaro et al., 2021; Gonzalez-Ollauri et al., 2023).
Smart cities	8	12	(Dushkova and Haase, 2020; Liu et al., 2021; Romero, 2023; Kauark-Fontes et al., 2023).
Adaptation to extreme heat events	7	11	(van den Bosch et al., 2022; Bresciani et al., 2023; Calabrese et al., 2023; Van Rompaey et al., 2023).
Economic stimulus	4	6	(de Luca et al., 2020; Kumar et al., 2020a,b; Nunes et al., 2021; García del Hoyo, 2021).
Communication or awareness	3	5	(Wild et al., 2020; Boogaard, 2021; Baykal and Topal, 2022).
Soil sustainability	2	3	(Fernández et al., 2018; Silvia et al., 2021).

Sources: Authors' own elaboration.

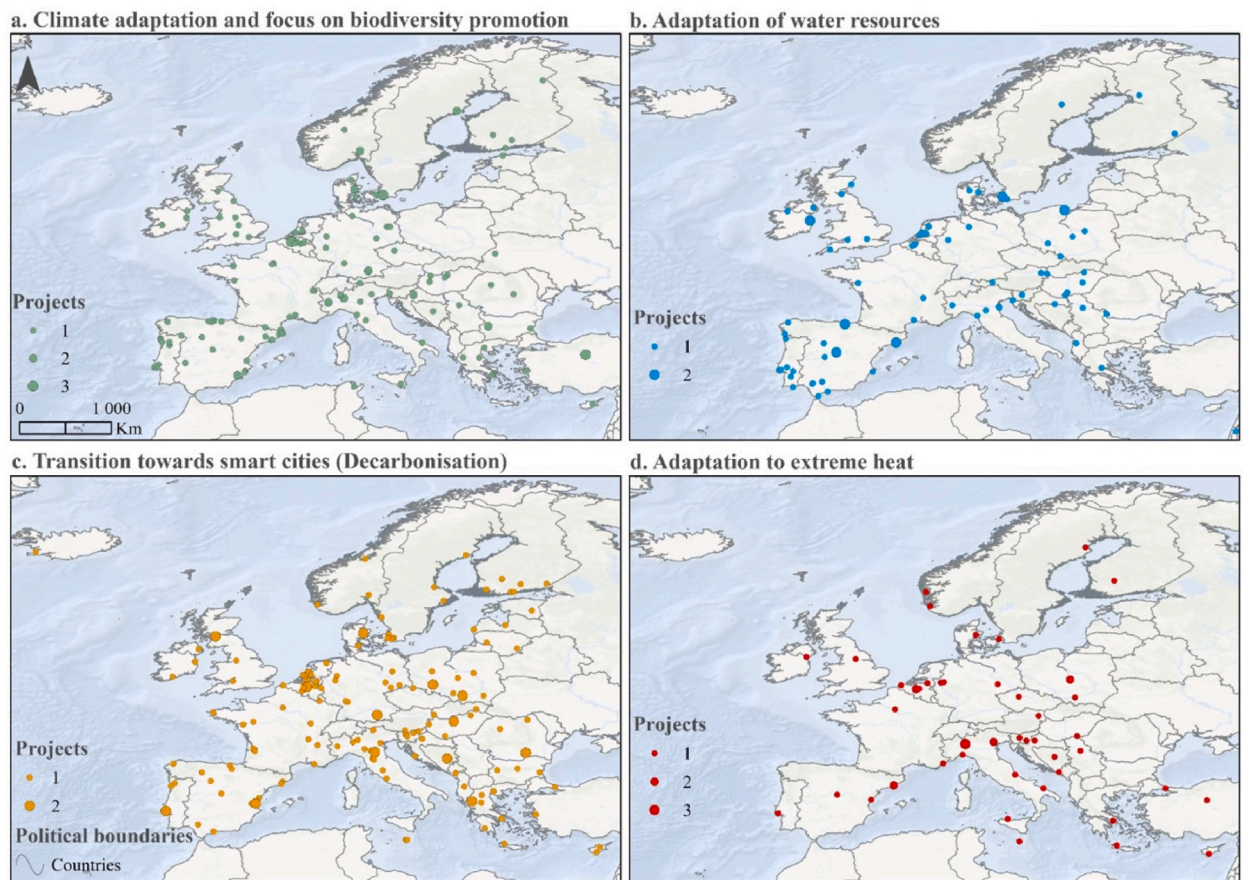


Fig. 6. Distribution of projects falling within the four main categories: climate adaptation and biodiversity promotion (a.), water resources (b.), Nature-based Solutions for the transition towards smart cities (c.), and extreme heat (d.).

Sources: Authors' own elaboration.

weight of extreme heat in the south, urban decarbonization in dense contexts, and water management in areas exposed to hydro-meteorological extremes. The preponderance of initiatives centered on acclimatizing to extreme heat in southern Europe and catalyzing the transition toward smart cities in densely populated regions can be ascribed to a confluence of factors. These include hot and dry climates, high population density, vulnerability to climate change, and region-specific political and investment priorities (Brandimarte and Borgström, 2024). In regions characterized by hot and dry climates, such as southern Europe, urban areas encounter significant challenges due to rising temperatures, which amplify the effects of the UHI phenomenon. These challenges are particularly acute in areas with high population density, where traditional infrastructure is inadequate to ensure the comfort and safety of residents. Conversely, smart cities employ technological solutions to optimize resource management and promote energy efficiency, thus mitigating the deleterious effects of heatwaves (Joshi et al., 2024; Parihar and Birman, 2024).

It is likely that Nbs initiatives will continue to focus on these four categories as Europe seeks to address environmental challenges, promote sustainability, and lead the implementation of Nbs initiatives. It is important to adapt strategies and approaches according to the specific needs of each geographical area to ensure an effective and integrated response to environmental challenges.

3.4. Methods and technologies used in the projects included

The review of the 66 projects highlights a diverse set of methodologies and technologies or practices used to advance the projects (Fig. 7). On the technological side, notable examples include (Fig. 7a).

- i) Monitoring technologies (e.g., IoT sensors, drones, and satellites) and climate risk management systems (e.g., early warning systems) stand out ($n = 31$), along with green technologies and ecological engineering solutions ($n = 21$), showing a clear trend towards integrated and sustainable approaches (*LIFE in the city*, *LIFE METRO ADAPT*, *LIFE-IP URBAN KLIMA*, 2050).
- ii) Green infrastructure, such as ecological corridors, retention basins, and hybrid solutions are also widely adopted ($n = 29$), alongside circular economy practices ($n = 5$) (*LIFE22-CCA-NL-GreenLED*, *LIFE22-CCA-NL-LIFE WATERSOURCE*, and *LIFE22-CCA-SE-LIFECAPEable*).

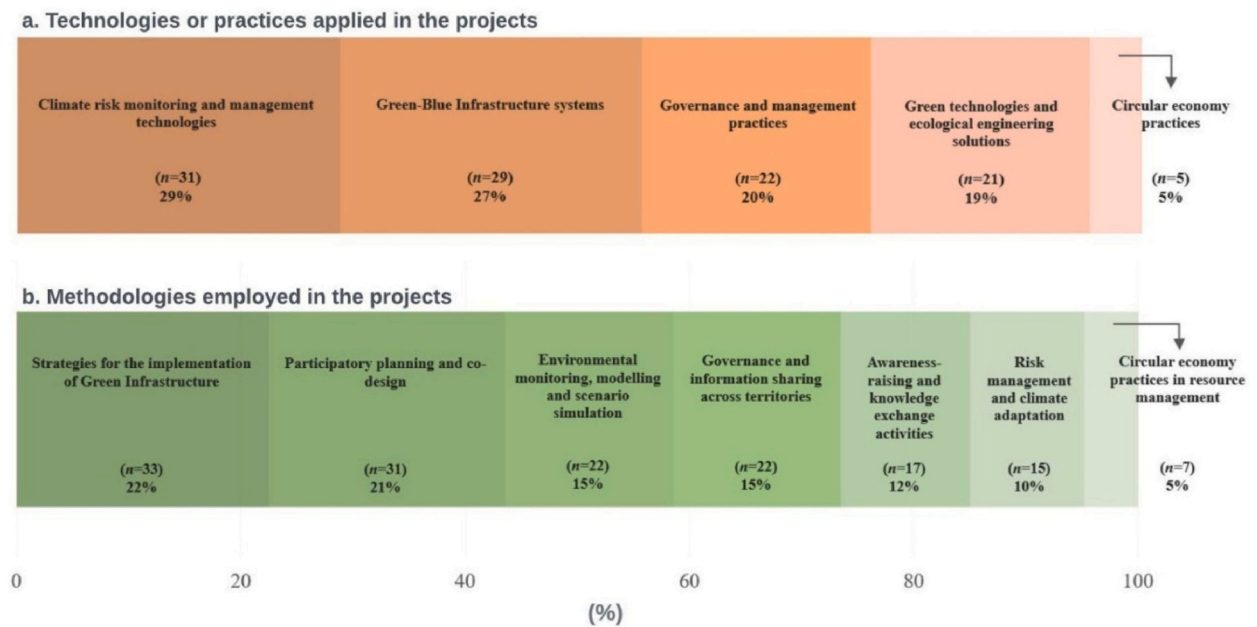


Fig. 7. Technologies/practices (a.) and methods (b.) applied in reviewed projects.

Sources: Authors' own elaboration.

- iii) Governance and management practices ($n = 22$) that propose a structured and systematic approach to developing and implementing solutions (*LIFE-CLIMCOOP*, and *Upsurge*).

Regarding project methodologies, several techniques are identified that underpin the implementation and success of the reviewed projects (Fig. 7b).

- i) Strategies for green infrastructure implementation ($n = 33$), and participatory planning and co-design (e.g., living labs, and co-design processes) ($n = 31$) (*LIFE21-CCA-PL-LIFECOOLCITY*, and *Life + A GreeNet*) and governance and information sharing across territories ($n = 22$) are widely used (*LIFE22-CCA-SE-LIFECAPEable*, and *LIFE IP ARTISAN*), indicating involvement of local stakeholders and the community at large to ensure that solutions are appropriate and accepted by the community.
- ii) Environmental monitoring, modelling, and scenario simulation ($n = 22$) also play a key role (*LIFE METRO ADAPT*, and *LIFE-IP URBAN KLIMA, 2050*), indicating the measurement of solution performance and its monitoring, allowing adjustments during implementation, and providing data to demonstrate their effectiveness
- iii) Awareness-raising and knowledge exchange activities ($n = 17$) to raise awareness of the importance of NbS and the benefits when implemented and how they can be used (*LIFE21-CCA-PL-LIFECOOLCITY*, and *LIFE22-CCA-PT-COOLIFEALMADA*).
- iv) Climate risk management and adaptation strategies ($n = 15$), as well as circular economy and resource management practices ($n = 7$), are reported. These latter initiatives frequently focus on ecosystem restoration and conservation, including the creation of protected areas, reforestation, and the rehabilitation of degraded land (*LIFE AGUA DE PRATA*, and *LIFE22-CCA-NL-GreenLED*).

Projects with a focus on biodiversity have been demonstrated to be more effective in reducing local vulnerabilities to climate change, particularly in densely urbanized areas where traditional solutions are economically unfeasible (*LIFE PollinAction*, *LIFE in the City*, and *LIFE METRO ADAPT*). Furthermore, the implementation of real-time monitoring technologies, including drones and IoT sensors, is a distinguishing feature of 31 projects. These technologies represent an innovative approach, facilitating continuous assessments and dynamic adjustments in the implementation of solutions (*LIFE21-CCA-PL-LIFECOOLCITY*, *Upsurge*, and *Phusicos*). A notable element pertains to the implementation of collaborative methodologies, exemplified by the integration of living labs in 47 % of the projects, namely *SCORE*, *DivAirCity*, and *UNALAB*. These initiatives have been shown to foster stronger community engagement and enable observer cities to gain insights and learn from the interventions. This, in turn, contributes to local acceptance and the transfer of knowledge.

The combined use of monitoring technologies, green infrastructure systems, and participatory governance practices indicates that the effectiveness of NbS depends on the articulation between technological innovation and inclusive social processes. The emphasis on living labs and participatory co-design, present in almost half of the projects, confirms the role of NbS as spaces for experimentation and collective learning. This aligns with studies that highlight the importance of knowledge co-production and community participation for the acceptance and legitimacy of NbS (Nunes et al., 2021; Hölscher et al., 2024).

3.5. Challenges in project implementation

The analysis of NbS typologies in the projects identifies three main categories (Fig. 8): BGI or ecosystem creation ($n = 28$), restoration of degraded ecosystems ($n = 23$), and conservation practices of existing ecosystems ($n = 14$) (Fig. 9a). This classification follows the main NbS categories proposed by the IUCN, emphasising the achievement of net biodiversity gains, as recommended in its reference framework (IUCN, 2020). Each typology requires different strategies, ranging from the integration of natural elements in urban environments to the sustainable of degraded areas, reflecting a multifaceted commitment to ecosystem protection and resilience (Dushkova and Haase, 2020).

In terms of expected impacts (Fig. 9b), projects report biodiversity and habitat promotion ($n = 38$), climate adaptation and resilience (e.g., to extreme weather events), ecological resilience (e.g., coastal protection) ($n = 36$), improved habitability and acoustic conditions, social inclusion and well-being ($n = 27$), enhanced water quality and availability ($n = 18$), reduced air pollutants (e.g., carbon dioxide and greenhouse gases) and improved air quality ($n = 17$), adoption of circular economy practices (e.g., waste valorisation, efficient resource use, pollution reduction) ($n = 15$), public health benefits ($n = 10$), and cultural heritage preservation ($n = 6$).

The projects also involve diverse community groups (Fig. 9c) – businesses, citizens, civil society/NGOs, governmental entities, the scientific community, and schools (e.g., children, teachers, and staff) – confirming the inclusive and collaborative approach required to meet objectives and foster sustainability.

With respect to implementation challenges (Fig. 9d), key issues include the replication of effective solutions ($n = 24$), cooperation and coordination across territorial units ($n = 17$), behavioural change and community engagement ($n = 15$), and funding and access to decision-making tools ($n = 12$). These critical factors indicate that, despite the potential of NbS, their dissemination and consolidation depend on overcoming governance, social mobilisation, and financial sustainability barriers.

The challenges identified in this study range from the replication of solutions to the mobilization of continuous funding. These challenges reflect that the barriers are not merely technical but, above all, institutional and social. The necessity for interterritorial cooperation, as well as the active involvement of communities and target groups, underscores the pivotal role of governance as a critical element for the sustainability of NbS. This pattern aligns with the extant literature, which identifies the lack of stable financing mechanisms and political coordination as recurrent obstacles to the mainstreaming of NbS (Scolobig et al., 2023).

4. Conclusions

The study employed a systematic review of projects, following the PRISMA guidelines, to analyse 66 EU-funded projects developed between 2014 and 2023. Its aim was to understand the practical applications of NbS in urban and peri-urban environments. The analysis revealed the predominance of initiatives addressing climate change adaptation, focusing particularly on biodiversity, water resource management, the transition toward smart cities, and the mitigation of extreme heat impacts. These four categories emerged as the main categories of NbS project objectives. The geographical distribution of projects indicates a higher concentration in Southern Europe and in densely populated urban areas, which are both highly vulnerable to climate change and attractive for strategic investments. Despite this diversity, innovative methodologies such as real-time monitoring technologies, living labs, and co-creation processes were also observed, strengthening knowledge transfer and social acceptance. Furthermore, the scale of implementation proved to be a decisive factor: local projects enhanced community involvement and generated immediate effects, while regional and national interventions demonstrated greater potential to influence public policies and guide long-term investments.

The findings also highlight the growing importance of NbS in responding to environmental and social challenges, particularly in the

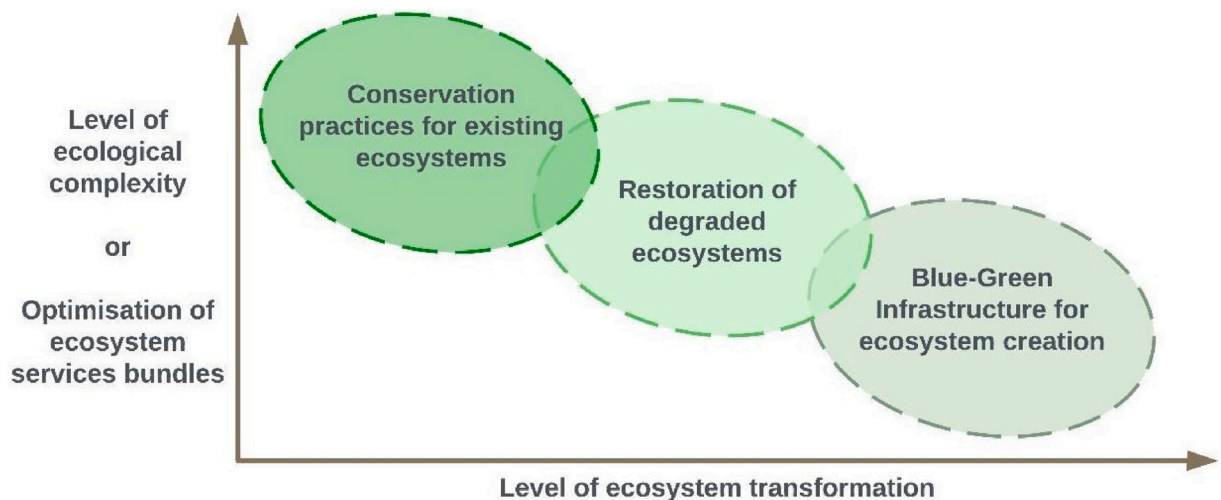


Fig. 8. Categories of Nature-based Solutions proposed, with an emphasis on achieving a net-gain in biodiversity.

Sources: Adapted from IUCN (2020).

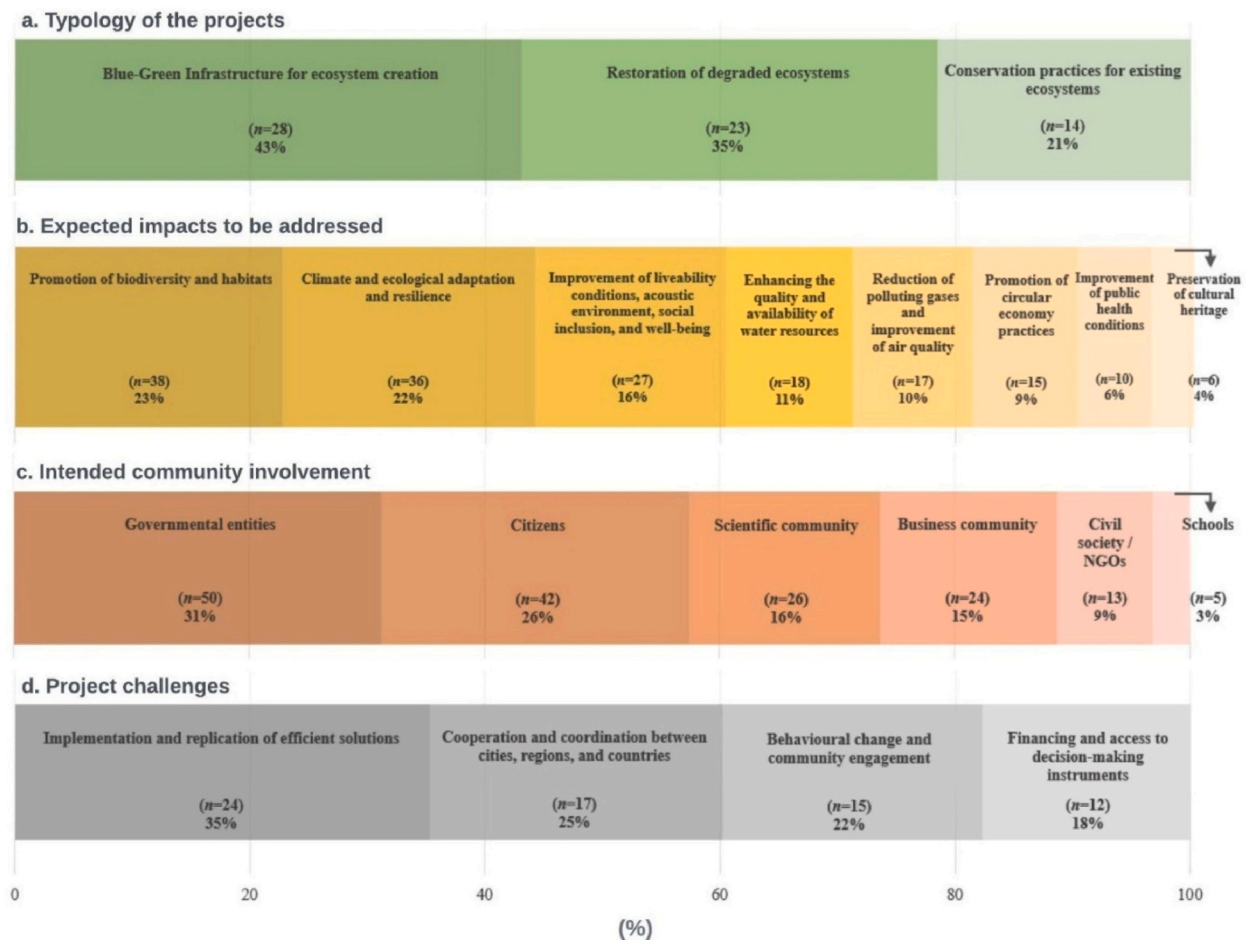


Fig. 9. Typology (a.), expected impacts addressed (b.), target community involvement (c.), and challenges (d.) of the projects included in the review.

Sources: Authors' own elaboration.

wake of the COVID-19 pandemic, which underscored the links between access to natural spaces, public health, and urban resilience. Overall, the study confirms the strategic role of NbS as multifunctional instruments that can foster resilience, sustainability, and innovation in urban public policies.

Despite these contributions, some limitations should be acknowledged. The reliance on specific databases for project collection may have excluded locally driven initiatives without external funding, potentially leading to a biased samples of the projects analysed. In addition, some projects lacked accessible website, which restricted the availability of information on objectives, methodologies, and challenges encountered.

To overcome these limitations, future research should employ complementary approaches such as participatory mapping, collaboration with community networks, consultation of municipal and regional reports, and fieldwork, which would help capture local initiatives not formally registered but still capable of generating significant environmental, social, and economic benefits. It is also important to strengthen intra-country comparative analyses (north-south, urban-rural), integrate economic dimensions to explain regional disparities, and develop robust impact assessment metrics, including cost-benefit analyses. Lessons from the COVID-19 pandemic crisis further emphasize that urban resilience depends not only on access to green spaces but also on stable collaborative processes, underscoring the need to integrate NbS into long-term policy frameworks and public health strategies.

CRediT authorship contribution statement

Inácio Ribeiro: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hélder Silva Lopes:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Funding acquisition, Formal analysis, Conceptualization. **Paula C. Remoaldo:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Vítor Ribeiro:** Writing – review & editing, Validation. **Juliana Araújo Alves:** Writing – review &

editing. **Lígia Silva:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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