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Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services

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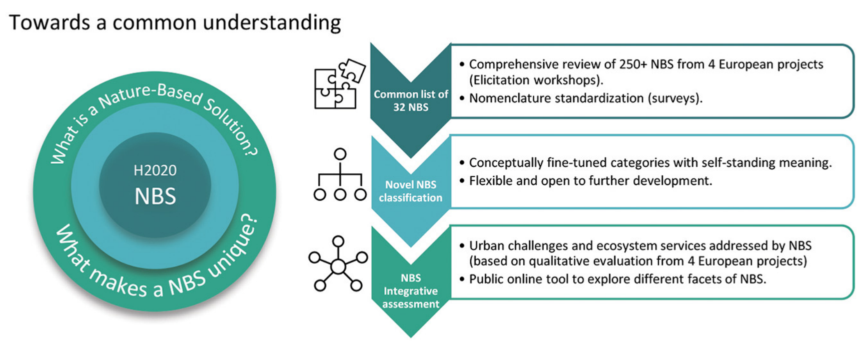
HIGHLIGHTS

- *Motivation:* A Lack of a common conceptualization of Nature-Based Solutions (NBS)
- *Methodology:* Mixed quantitative-qualitative to merge results from 4 European projects
- *Outcomes:* A list of 32 NBS, a nomenclature, a novel classification and assessment
- *Key findings:* The 'green factor' and non-intensive actions are key criteria for identifying a solution as an NBS.
- *Further research:* Discerning NBS and planning approaches

GRAPHICAL ABSTRACT



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ABSTRACT

The concept of Nature-Based Solutions (NBS) has emerged to foster sustainable development by transversally addressing social, economic, and environmental urban challenges. However, there is still a considerable lack of agreement on the conceptualization of NBS, especially concerning typologies, nomenclature, and performance assessments in terms of ecosystem services (ES) and urban challenges (UC). Therefore, this article consolidates the knowledge from 4 European projects to set a path for a common understanding of NBS and thus, facilitate their mainstreaming. To do so, firstly, we performed elicitation workshops to develop an integrative list of NBS, based on the identification of overlaps among NBS from different projects. The terminologies were formalized via web-based surveys. Secondly, the NBS were clustered, following a conceptual hierarchical classification. Thirdly, we developed an integrative assessment of NBS performance (ES and UC) based on the qualitative evaluations from each project. Afterwards, we run a PCA and calculated the evenness index to explore patterns among NBS. The main conceptual advancement resides in providing a list of 32 NBS and putting forward two novel NBS categories: NBS units (NBS_u) that are stand-alone green technologies or green urban spaces, which can be combined with other solutions (nature-based or not); NBS interventions (NBS_i) that refer to the act of intervening in existing ecosystems and in NBS_u, by applying techniques to support natural processes. The statistical analysis suggests that NBS_u are more versatile than NBS_i in terms of UC and ES. Moreover, the results of the integrative assessment of NBS performance suggest a greater agreement concerning the role of NBS in addressing

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environmental UC, cultural and regulating ES than regarding socio-economic UC and supporting and provision ES. Finally, the 'green factor' and the replication of non-intensive practices occurring in nature seem to be key criteria for practitioners to identify a particular solution as an NBS.

1. Introduction

More sustainable and resilient cities have been increasingly associated with a gradual (re) integration of nature into urban areas, overturning the dominance of grey infrastructure in city landscapes (Lafortezza et al., 2018). In this context, the concept of Nature-Based Solutions (NBS) has gained considerable popularity as it is deemed to facilitate the transition towards greener, more resilient and socially inclusive cities. The European Commission (EC) definition of NBS takes a broad perspective, referring to the three pillars of sustainability - economic, environmental and social (European Commission, 2015), while the International Union for Conservation of Nature (IUCN) definition (Cohen-Shacham et al., 2016) emphasizes actions for conservation and restoration (Albert et al., 2019; Carsten et al., 2017). Given the relative novelty of the concept and its accelerated uptake, it is no surprise that more definitions have arisen in the past years (Maes and Jacobs, 2017; van der Jagt et al., 2017; Short et al., 2019; Albert et al., 2019; for a review see Sarabi et al., 2019 and Carsten et al., 2017). Recently, the COST Action "Circular City" proposed a definition bringing a conceptual added value: It transfers the NBS concept into urban areas, putting a special emphasis on resource circularity (Langergraber et al., 2020).

Nevertheless, this definitional 'wealth' and a lack of agreement on specific characteristics, unique to NBS (Dorst et al., 2019; Carsten et al., 2017), has led to a confusion within the NBS community concerning what is and what is not an NBS. The framing of the NBS concept does not always distinguish it from other well-established environmental concepts - such as ecological engineering, green infrastructure, urban green (and blue) spaces, and ecosystem-based adaptation, with which NBS shares key elements (Almenar et al., 2021; Sarabi et al., 2019). While the IUCN states that NBS is an umbrella concept that encompasses these similar approaches (Cohen-Shacham et al., 2016), others appeal to the need for a separate definition of NBS (Sarabi et al., 2019; Dorst et al., 2019; Carsten et al., 2017). The vagueness of NBS semantics is reflected in the way that different sets of NBS are classified and assessed in terms of Urban Challenges (UC) and Ecosystem Services (ES), especially in the framework of projects funded under the European Horizon 2020 (H2020) program. Moreover, there is a lack of agreement concerning the terminology used to refer to specific NBS. This means that one NBS may be referred under several different names. For example, while some authors may use the term "green façade with climbing plants" (URBANGREENUP, 2018), others might describe the same NBS as a "climber green wall" (NATURE4CITIES, 2020; Somarakis et al., 2019), and yet others may refer to this as "ground-based greening"(UNALAB, 2019) or green façade (Manso and Castro-Gomes, 2015).

Therefore, to address this gap, the aim of the paper is to take a step towards a common understanding of the NBS typologies, terminologies, classification and evaluation. To do so, in this paper we integrate the vast knowledge across NBS reported in recently completed or ongoing H2020 European projects. We adopt a mixed quantitative-qualitative methodology (dedicated workshops, interviews with experts, surveys and statistics) with the following specific objectives: i) to facilitate communication and knowledge-sharing across the NBS community by producing a common list of NBS with a nomenclature based on surveyed practitioners preferences; ii) to contribute to the conceptualization of NBS and its mainstreaming by providing a novel and used-friendly classification scheme as well as insights on what defines a solutions as a Nature-based one iii) to overview how the European NBS community evaluates the performance of NBS in terms of UC and ES by providing an integrative assessment based on the qualitative evaluation of each project.

2. Methods

The study was divided into 3 main parts: i) development of a common list of NBS (Section 2.1) across H2020 projects through 2 elicitation expert workshops, ii) building consensus on NBS terminology and classification through two worldwide surveys (Section 2.2), and iii) development of an integrative assessment framework for UC and ES through statistical analysis of existing scores given in existing H2020 projects (Section 2.3).

2.1. Common list of NBS

Our first endeavor was to put together a common list of NBS considering the existing NBS from four European projects. The selected projects were URBANGREENUP (GU), UNALAB (UNL), NATURE4CITIES (N4C) and THINKNATURE (TN), according to the following criteria: (i) funding under H2020 program from at least two different NBS recent calls (2016–2017) (ii) projects should provide an NBS classification scheme including nomenclature and/or description; and (iii) projects should have performed an assessment of NBS in terms of their ability to address urban challenges (UC) and/or provide ecosystem services (ES). We performed a comprehensive review of public documents from these projects (URBANGreenUP, 2018; UNALAB, 2019; NATURE4CITIES, 2020; Somarakis et al., 2019). The initial list of potential NBS was restricted to those with a performance assessment of UC and ES. Then, a face-to-face elicitation workshop (adapted from IDEA protocol, Hemming et al. (2018)) brought together 60 NBS experts during the annual meeting of the COST Action "Circular City" (https://circular-city.eu/) beginning of March 2020. The workshop was organized in 6 rounds of 4 parallel sessions, each with 15 participants and 1 moderator. The participants randomly changed sessions at each round. The agenda included the following steps:

i. Experts were first asked to reflect on the following questions: *what is and what is not an NBS? If it is not an NBS, what is it then? Why is it not an NBS?* This conceptual reflection was based on NBS definitions (European Commission, 2015; Cohen-Shacham et al., 2016; Langergraber et al., 2020). Those items not fitting the conceptualization were discarded.
ii. Identifying similar or identical NBS within projects, based on agreed-upon criteria: similar or equal role of nature (natural process occurring); similar or equal technical/design requirements (i.e. elements, costs, materials); similar or equal implementation scale; similar or equal benefits. The NBS that were found to be very similar/equal were considered as one NBS. Finally, only those NBS considered similar/equal across a minimum of 2 different projects were selected, in order to ensure robustness and to have assessment data from different sources. If needed, a group of NBS experts (within the network of the COST Action – "Circular City") was consulted to analyse NBS in which the consensus was not achieved.

In June 2020 an online elicitation workshop was held to validate procedures for achieving the list of NBS as well as the list itself.

2.2. NBS common terminology and classification

Two web-based surveys were launched to collect NBS expert preferences with regard to terminology. In order to ensure a high quality of responses, for both surveys, the respondent could only choose one option and answer only once per survey. The survey was published in OPPLA, the online EU repository of NBS (see https://oppla.eu/nature-based-solutions-terminology-survey; https://oppla.eu/lets-talk-same-nature-based-language-again) and disseminated through other NBS related networks (https://circular-city.eu/, https://snapp.icra.cat/, https://www.edicitnet.com/). In the first survey, a unified description was provided for each NBS based on the information of NBS considered as very similar or equal. The unified description and potential names for the NBS were obtained from the four H2020 projects by consulting public documents (NATURE4CITIES, 2020; Somarakis et al., 2019; UNALAB, 2019; URBANGREENUP, 2018). Respondents were asked to choose between the most suitable names offered for a specific NBS description or to suggest an alternative name. The criterion to select the names was that they received at least 50% of the valid votes (excluding declines and comments). For the cases in which none of the available names for a NBS received at least 50% of the votes, a second survey was launched, which included a thorough description (based on literature and suggestions from the first survey) of the two highest ranking names. For the second survey, the one sample chi-square test based on *P*-value method with 0.05 level of significance was applied to each NBS to determine if there was a significant difference in the proportion of respondents preferring one of the two names. For those NBS where no clear preference could be established through the statistical analysis of the survey, the final names were defined by the following steps:

i. **Counting the number of publications in Scopus containing the surveyed names** (two most voted names from the surveys). The Scopus search took place in October of 2020. Our criterion was to adopt the name with a minimum of 10 articles. Moreover, names should distinguish NBS from other existing natural ecosystems or other NBS.
ii. **Direct experts' consultation**, only for those NBS in which the name could not be defined in the previous step. In this case, we checked the number of publications in Scopus containing the names suggested by experts against the number of publications containing the surveyed names. The criteria to define the final name was a balance between number of publications and names that properly distinguished a particular NBS from others NBS or natural ecosystems.

A **3-level hierarchical classification** scheme for the NBS was proposed. The **first level** of the classification scheme was built on 3 existing categories proposed by Eggermont et al. (2015) which are: Type 1 represents no or only minimal intervention in ecosystems, with the objectives of maintaining or improving the delivery of a range of ES, both inside and outside of these preserved ecosystems (e.g. protection of mangroves; marine protected areas); Type 2 corresponds to the definition and implementation of management approaches that develop sustainable and multi - functional ecosystems and landscapes, which improves the delivery of selected ES compared to what would be obtained with a more conventional intervention (e.g. planning of agricultural landscapes; enhancing tree species and genetic diversity); Type 3 constitutes the managing of ecosystems in very intrusive ways or even creating new ecosystems (e.g., artificial ecosystems like green walls and green roofs). The fit into these categories was based on literature findings (Almenar et al., 2021; Sarabi et al., 2019) and experts' interpretations of the Eggermont et al. (2015) categories. The **following two levels** of the new classification were identified by interviewing experts and scanning literature for similarities and differences between the NBS at hand in terms of features, type of vegetation employed, scale of implementation and purpose.

As a general rule, the following criteria were applied to all levels of the classification: 1) an NBS can only fit into one category; 2) all categories have descriptive names (self-standing meaning) and 3) all categories have to be translatable into simple questions as a guidance for using and further developing the classification.

2.3. Integrative assessment framework for urban challenges and ecosystem services

The integrative assessment of UC and ES was organized in two steps: Calculation and visualization of crossed scores (Section 2.3.1) and multivariate analysis (Section 2.3.2).

2.3.1. Calculation and visualization of crossed scores

Each of the four selected H2020 projects presented a different list of UC and ES. Hence, we first established a baseline for UC, based on the list proposed in the Eklipse framework (Raymond et al., 2017), and for ES based on TEEB (2011) and Millennium ecosystem assessments (Alcamo et al., 2003; Reid et al., 2005). Next, we related the UC and ES of each project to this baseline. For example, project UNL uses 3 water-related challenges: water scarcity, flood management and water pollution. These challenges were related to the Eklipse challenge “Water management”. The same procedure was performed for ES (please see supplementary data: Fig. A.1 and Table A.1). This allowed us to establish a common framework for UC and ES assessments. Secondly, we calculated the normalized raw scores for each individual NBS based on the information available in public documents of each project (qualitative approaches: Ecosystem Services Assessment approach, panel of experts or experts consultation, literature review and ect) by using binary logic (score 1 when the NBS addressed UC or ES and score 0 when the NBS did not address UC o ES). Next, we calculated the final scores for each of UC and ES. For example, the score for the UNL set of NBS regarding the water management challenge was based on the average of normalized scores for related challenges such as water scarcity, flood management and water pollution. Thirdly, we calculated crossed scores by simply averaging using the normalized raw scores from the NBS considered either as very similar or equal. Finally, a tool was developed using ShinyR package (Chang et al., 2020) on R v. 3.6.3 (R Core Team, 2020) and the ggplot2 package (Wickham, 2016) to visualize the outcome of the UC and ES scores per NBS (find the source-code of the tool in https://github.com/icra/nbs_list).

2.3.2. Multivariate analysis

Principal component analysis (PCA) on the UC and ES for all NBS was conducted to explore similarities among NBS and identify which UC and ES were driving those similarities. Data pre-treatment was conducted to avoid biases due to missing values. UC with more than 1 missing value (not assessed for any NBS) were hampered and ES were grouped per type: regulation, provision, cultural and supporting. The package FactoMineR in R (Lê et al., 2008) was used to run the PCA analysis and missMDA package in R (Josse and Husson, 2016) for dealing with missing values. We used the Pielou's evenness index to express which NBS were the most balanced in terms of performance against different facets (UC and type of ES). The evenness index was calculated using the Vegan package in R (Oksanen et al., 2019) as follows:

$$evenness_i = \frac{diversity_i}{\log scores_i} \quad (1)$$

where *i* is a specific NBS, *diversity* is calculated as a Shannon index and *scores* is the number of variables (crossed scores on UC and ES) in which the *NBS* has a score bigger than 0. To calculate the evenness index, the missing values were replaced by zeros.

3. Results

First, we present the results of the participatory approach applied to develop the common list of NBS (Section 3.1). Second, we propose a set of names and a novel classification for the NBS included in the list (Section 3.2). Finally, we present the main results of the integrative assessment and multivariate analyses (Section 3.3).

3.1. Common list of NBS

The exercise started with more than 250 NBS collected from the four selected H2020 projects. An iterative process was followed to select the ones which i) included an assessment in terms of UC and ES, ii) were considered an NBS, and iii) showed obvious overlapping (similar/equal NBS across different projects) (Fig. 1).

As can be seen in Fig. 1, a total of 62 potential NBS were excluded for not being considered an NBS. The exclusion of such items was based on the following justifications (see Table A.2): 3 items were found to be a benefit that any NBS could provide, depending mainly on the selection of plant species (e.g. "Cooling trees"); 9 items were found to be inspired by nature, but not employing nature (e.g. "Permeable concrete"); 43 items were found to be supportive planning/management approaches to preserve existing ecosystems and to facilitate NBS implementation, monitoring and its sustainable continuation (e.g. "Limit or prevent some specific uses and practices"); 4 items were found to not be inspired or supported by nature since they were too intensive or did not occur in nature (e.g. "Small-scale urban livestock"); and 3 items were found to be a cluster/category of NBS that could include different NBS with the same purpose (e.g. "Natural wastewater treatment").

Out of the remaining 140 NBS, 33 NBS were excluded because they did not comply with the selection criteria of being similar/equal across at least 2 different projects. Out of the four premises provided to state similarity or equality among NBS, requirements in terms of design and scale implementation proved to be more relevant than benefits or replicating natural processes. Note also that some elements were seen as similar by experts while certain guidelines (University of Arkansas Community Design Center, 2010) consider them as separate NBS (e.g. "Detention ponds"and "Infiltration basins"). Finally, the main outcome of the elicitation workshop is a common list of 32 NBS which represent the 107 NBS from the four H2020 projects reviewed (25 NBS from GU; 30 from UNL; 31 from N4C; and 21 from TN, respectively). Table 1 shows the different names given to the NBS considered similar or equal, in each NBS of the H2020 projects.

3.2. NBS common terminology and classification

The first web-based survey gathered more than 160 participants from 46 countries worldwide and the second survey was answered by 92 participants from 30 countries. For both surveys, most of participants were researchers, engineers, architects, urban planners from europe (approx 70%), working in the NBS field for 1–5 years or even more than 5 years. As a result of the first survey, the names of 20 NBS were chosen by following the criteria of more than 50% of total valid votes (Table A.3 – in green). In turn, in the case of 12 NBS, none of the options received most votes (Table A.3 – in blue) and thus, a second web-based survey was carried out. As a result of the second survey, for 7 NBS there was a significant difference (chi-square test, 0.05 level of significance) in the proportion of respondents preferring one of the two options

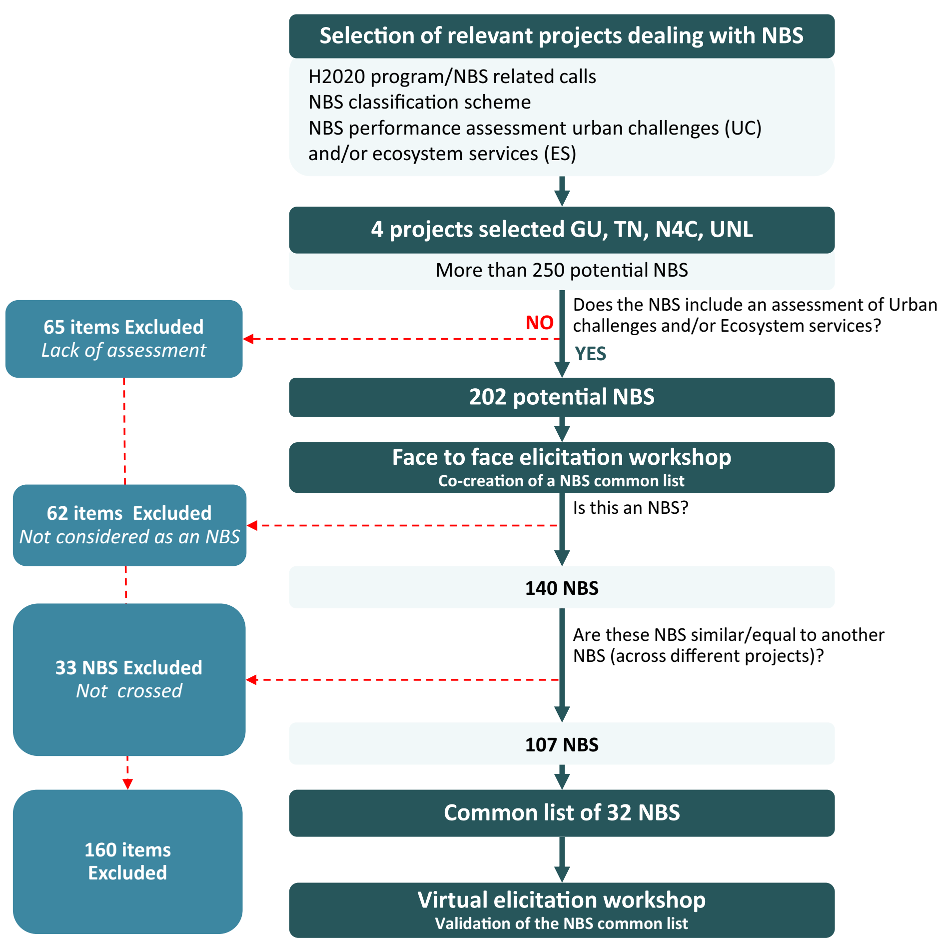

Fig. 1. Summary of the participatory approach applied to reach the common list of NBS.

Table 1
Common list of NBS and respective grouped/paired NBS (considered similar or equal across projects).

NBS	NBS (grouped or paired)			
	GU	UNL	N4C	TN
NBS1	Floodable park	Infiltration basin; (Dry) Detention Pond		
NBS2	Grassed swales and water retention ponds	(Wet) Retention Pond		
NBS3	Rain gardens	Rain gardens		
NBS4	Grassed swales and water retention ponds	Bioswale	Swale	
NBS5	Electro Wetland	Constructed wetlands	Constructed wetland for wastewater treatment	Use engineered reedbeds/wetlands for tertiary treatment of effluent
NBS6	Green façade with climbing plants	Noise barrier as ground-based greening; Ground-based greening	Climber green wall	Climber green wall
NBS7	Hydroponic green façade; Green noise barriers	Façade-bound greening	Green wall system	Green wall system
NBS8	Vertical mobile garden	Mobile vertical greening / Mobile Green Living Room		
NBS9			Planter green wall	Planter green wall
NBS10	Green shady structures		Vegetated pergola	
NBS11	Green roof; Green covering shelters	Extensive green roof; Constructed wet roof	Extensive green roof	Intensive green roof/Semi-intensive green roof/Extensive green roof
NBS12	Green roof	Intensive green roof	Intensive green roof	Intensive green roof/Semi-intensive green roof/Extensive green roof
NBS13		Smart roof	Semi-intensive green roof	Intensive green roof/Semi-intensive green roof/Extensive green roof
NBS14	Natural pollinator's modules; Compacted pollinator's modules		Create and preserve habitats and shelters for biodiversity	Create and preserve habitats and shelters for biodiversity
NBS15	Planting and renewal urban trees; Trees re-naturing parking	Single line trees; Boulevards	Street trees; Single tree	Street trees
NBS16		Green Corridors		Green corridors and belts
NBS17	Green resting areas	Residential park	Large urban public park	Large urban park
NBS18	Green resting areas; Parklets		Pocket garden/park	Pocket garden/park
NBS19	Arboreal areas around urban areas	Group of trees	Wood; Urban forest	Urban forest
NBS20			Heritage garden	Heritage park
NBS21			Private gardens	Private gardens
NBS22			Vegetables gardens	Community garden; Vegetable gardens
NBS23	Urban orchards		Urban orchard	Urban orchards
NBS24			Use of pre-existing vegetation	Use of pre-existing vegetation
NBS25	Community composting		Composting	
NBS26	Enhanced nutrient managing and releasing soil; Smart soil as substrate		Soil improvement; Structural soil; Mulching	Soil improvement and conservation measures; Incorporating manure, compost, biosolids, or incorporating crop residues to enhance carbon storage
NBS27			Soil & slope revegetation; Strong slope vegetation	Systems for erosion control
NBS28		Living Fascine; Living revetment; Revetment with cuttings (Spreitlage); Planted embankment mat	Vegetation engineering systems for riverbank erosion control	Systems for erosion control
NBS29	Hard drainage-flood prevention Unearth water courses	Reprofiling the channel cross-section; Channel widening and length extension; Daylighting	Reopened stream	Rivers or streams, including re-meandering, re-opening Blue corridors; Systems for erosion control
NBS30		Branches; Reprofiling/Extending flood plain area	Floodplain	
NBS31	Hard drainage-flood prevention Unearth water courses	Diverting and deflecting elements		Systems for erosion control
NBS32	Green parking pavements; Cycle-pedestrian green pavement	Vegetated grid pave	Green parking lot	

provided (Table A.4 – in green). In contrast, for five NBS no significant difference was noticed: NBS 4, 5, 6, 28 and 30 (Table A.4 - in blue). For NBS 4 and 5, the name selected was the one more commonly used in scientific publications, “Swale” and “constructed wetland”, respectively. Moreover, both names can discern such NBSs from others similar NBS or even existing natural ecosystems such as natural constructed wetlands. For NBS 30, even though the name “Floodplain” had a higher number of scientific citations than “Reprofiling/Extending floodplain area”, both coming for the survey, the latter name was selected because it distinguishes this NBS from naturally formed floodplains. For NBS 6, the surveyed names “Green façade with climbing plants” and “climber green wall" were encountered in, respectively 0 and 4 documents in Scopus. Therefore, two options were provided by experts: “Soil-based green façade” and “green façade”. No documents were found in Scopus for “Soil-based green façade” and more 236 documents included the name “green façade”. Therefore, the later name was adopted because it was encountered in a higher number of articles than the surveyed names and it has been widely applied in literature to differentiate this type of green wall from other typologies (Manso and Castro-Gomes, 2015; Widiastuti et al., 2020; Wang et al., 2020; May Tzuc et al., 2021). For NBS 28, none of the surveyed names have been commonly cited in scientific literature (less than 10 documents were found). Therefore, “Systems for erosion control” was discarded since it does not specify the site in which this intervention will take place, which may cause confusion and difficulties to discern this NBS from others focused on erosion control. In contrast, “Vegetation engineering systems for riverbank erosion control” (surveyed name) and “Riverbank engineering” (suggested by experts) indicate the site of intervention (riverbank). The latter option was selected, since it appeared in a slightly higher number of publications than the other. The results of Scopus search can be seen in supplementary data (Table A.5).

The 32 common NBS (Table 2) were classified following a hierarchical structure of 3 levels (Fig. 2). The first level distinguishes between **NBS units (NBS_u)** (Eggermont et al., 2015 - Type 3) **and NBS interventions (NBS_i)** (Eggermont et al., 2015 - Type 2).

NBS_u are green technologies or green urban spaces, either autonomous or integrated in a larger ensemble - i.e. combined with other NBS, grey infrastructures or conventional technologies - thus forming complex "living" systems. NBS_u can be part of existing urban green/blue infrastructure or they can be built from scratch. Finally, these units are capable of replicating processes occurring in nature to enhance the performance of natural capital in cities and thus, provide a wide range of ecosystem services and co-benefits.

NBS_i refer to the act of intervening in specific ecosystems or in other NBS_u by applying measures or techniques to support natural processes and biodiversity. Even though NBS_i can provide diverse co-benefits, they are usually applied to achieve specific purposes (e.g. preserve/maintain natural capital, improve soil quality, prevent/control erosion).

Within the NBS_u, on the second level, a differentiation is made between spatial and technological units. **NBS spatial units (NBS_{su})** comprise different elements of urban blue/green infrastructure, mainly related to types of urban green spaces (e.g. parks, gardens, orchards, corridors, forest) or single elements such as street trees. These units are usually implemented on the ground and can provide a plethora of co-benefits. Out of 23 NBS_u, 9 were included in this sub-category since they are often referred to as “urban green spaces” (Holt and Borsuk, 2020; Rasli et al., 2019; Nastran, 2020). **NBS technological units (NBS_{tu})** include blue/green technologies that are meant to provide specific features and services (e.g. thermal insulation, shading, water infiltration, water treatment), and thus display a set of specificities in terms of design, implementation and monitoring. In contrast to NBS_{su}, NBS_{tu} can be implemented in a wide range of scales, from the ground to vertical empty spaces and rooftops. Moreover, NBS_{tu} can be combined with other NBS_u (spatial or technological) or with other advanced technologies (Maes et al., 2015; Depietri and McPhearson, 2017; Davies and Lafortezza, 2019). Out of 23 NBS_u, 14 NBS were assigned as NBS_{tu} as they are often referred to as “urban green *technologies*” or “green *technologies*” or simply “*technologies*” (Stefanakis, 2019; Bonoli and Pulvirenti, 2018; Sun et al., 2018).

On the third level, NBS_{su} and NBS_{tu} are respectively grouped according to forms of vegetation and scale of implementation. NBS_{su} are split in 2 sub-categories: **Spatial Arboreal Units (NBS_{sau})**, in which the component arboreal is the main form of vegetation; and **Spatial Mixed Vegetation Units (NBS_{smvu}),** in which a different form of vegetation (beyond trees) can be employed. NBS_{tu} are split in: **Technological Vertical Units (NBS_{tvu})**, which are implemented on a variety of vertical surfaces, from façades (of buildings) (Manso and Castro-Gomes, 2015; Perini et al., 2011; Manso and Castro-Gomes, 2015) to self-standing vertical surfaces anywhere in the city; **Technological Horizontal Units (NBS_{thu})** which are mainly implemented on horizontal surfaces, on the ground or on building rooftops.

On the second level, NBS_i are grouped according to their main purpose or site in which the intervention will take place, resulting in the following sub-categories: **River interventions (NBS_{ir})**, which includes a diverse set of techniques of fluvial/water bioengineering for river management in terms of flow dynamics, flood and erosion control; **Soil interventions (NBS_{is})**, which includes techniques of soil bioengineering to improve and maintain soil quality in terms of physical, chemical and biological features; **Biodiversity interventions (NBS_{ib})** which includes actions and measures for enhancing and preserving the natural capital in cities. The majority of NBS_i were considered river and soil interventions, mainly for being often referred to as soil and water bioengineering techniques (European Federation for Soil and Water Bioengineering, 2015; Rey et al., 2019). No third level was established for NBS_i.

3.3. Integrative assessment framework for urban challenges and ecosystem services

The integrative assessment framework returned a performance score of NBS between 0 and 1 for 10 UC and 19 ES, with the addition of the four corresponding categories of ES: Regulating, Cultural, Support and Provision. The complete set of results for each NBS can be explored

Table 2
NBS common list and terminology. The complete version of this table, including description and other possible names suggested through the survey or from existing guidelines, (can be seen in Table A.5).

Approach	Acronym	Name	Approach	Acronym	Name
2° survey	NBS1	Infiltration basin	2° survey	NBS17	Large urban park
1° survey	NBS2	(Wet) Retention Pond	1° survey	NBS18	Pocket garden/park
1° survey	NBS3	Rain garden	1° survey	NBS19	Urban forest
Mixed[a]	NBS4	Swale	1° survey	NBS20	Heritage garden
Mixed	NBS5	Constructed wetland	1° survey	NBS21	Private gardens
Mixed	NBS6	Green façade	1° survey	NBS22	Community garden
1° survey	NBS7	Green wall system	1° survey	NBS23	Urban Orchard
1° survey	NBS8	Vertical mobile garden	1° survey	NBS24	Use of pre-existing vegetation
1° survey	NBS9	Planter green wall	1° survey	NBS25	Composting
1° survey	NBS10	Vegetated pergola	2° survey	NBS26	Soil improvement
1° survey	NBS11	Extensive green roof	2° survey	NBS27	Systems for erosion control
1° survey	NBS12	Intensive green roof	Mixed	NBS28	Riverbank engineering
1° survey	NBS13	Semi-intensive green roof	2° survey	NBS29	Rivers or streams, including re- meandering, re-opening Blue corridors
1° survey	NBS14	Create and preserve habitats and shelters for biodiversity	Mixed	NBS30	Reprofiling/Extending floodplain area
1° survey	NBS15	Street trees	2° survey	NBS31	Diverting and deflecting elements
1° survey	NBS16	Green corridors	2° survey	NBS32	Vegetated grid pave

[a] Mixed: number of scientific publications (Scopus). In the cases in which a Scopus search was not conclusive, literature and experts were consulted (COST Action – "Circular City").

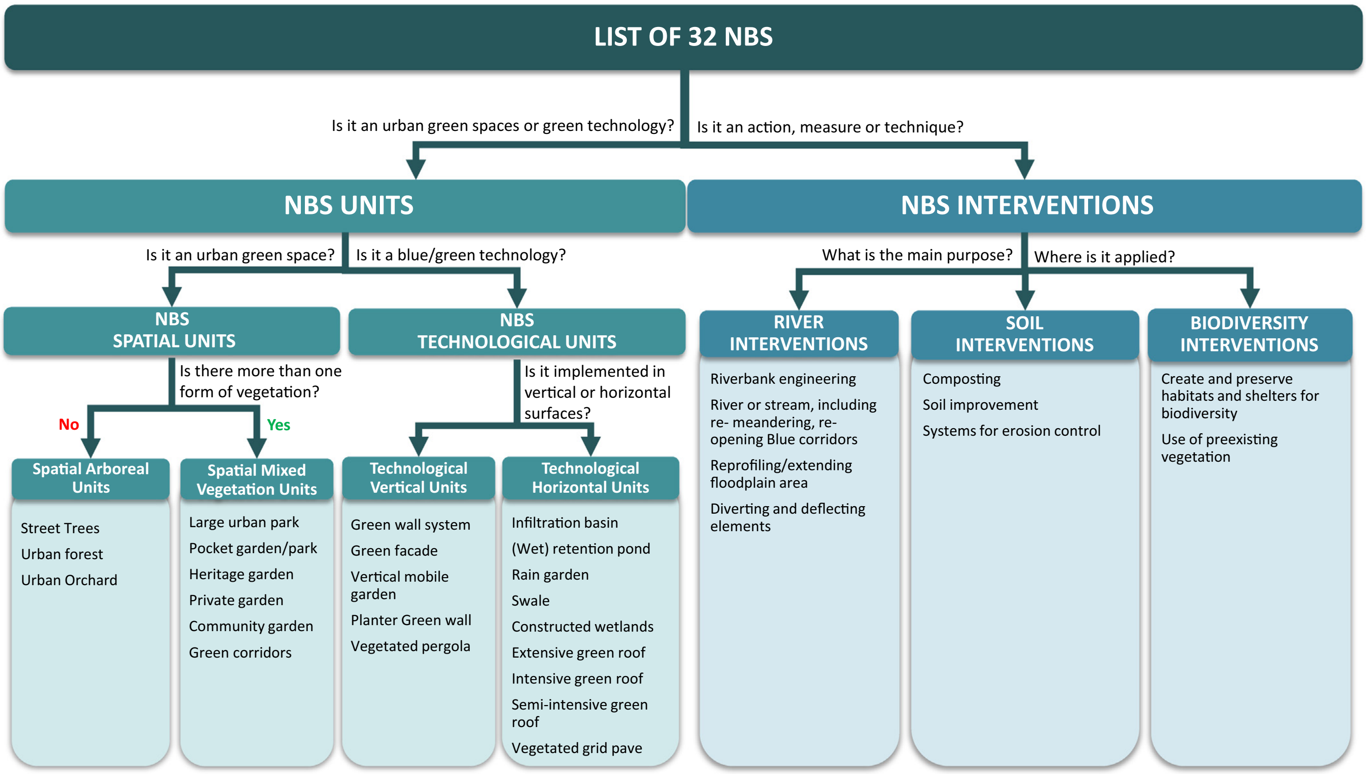

Fig. 2. A novel hierarchical classification of considered NBS.

on the tool: https://icra.shinyapps.io/nbs-list (an example is shown in Fig. 3).

The distribution of crossed scores through the different assessed challenges and services did not draw a clear pattern (Fig. 4). Some UC or ES presented a great diversity while others did not. Green space management is the highest-scoring UC, while public participation is the one with the lowest. Cultural ES is the highest-scoring category of ES, while provisioning's is the lowest-scoring category.

The PCA analysis shows that the first two dimensions accumulated 49.4% of model variance (Fig. 5). The first dimension is the linear combination of two NBS qualities: social and environmental UC, as well as cultural ES. The second dimension was divided by provisioning and supporting ES and water management in one direction and air quality, climate adaptation and economic opportunities in the other. The PCA outcome shows no obvious clustering of NBS. In addition, the categories of proposed hierarchical classification perform properly in the two dimensions of the PCA, with a few exceptions. Overall, NBS spatial scored well on social issues, climate resilience and air quality; likewise, technological units did not perform too well on water management, green management and cultural ES; finally, most of interventional NBS performed well in provision and supporting ES.

The evenness index for all NBS is shown in Fig. 6. All NBS scored between 0.85 and 1, thus, offering good overall performance addressing UC and providing ES. In general, NBS_u presented higher scores in the evenness index than NBS_i, showing that spatial and technological units tend to be more generalist, whereas NBS_i suit better for addressing specific UC and providing specific ES.

4. Discussion

This section puts forward a critical discussion about criteria raised during workshops to state if a solution is based on nature or not (Section 4.1). Next, we discuss the importance of having a common understanding of NBS terminology and classification in order to foment a path towards standardization (Section 4.2). Finally, we present a discussion about the integrative performance assessment (Section 4.3).

4.1. To be or not to be an NBS: What does it take?

The participatory approach employed in this research has revealed a set of insights on why a solution can be considered (as) a Nature-Based one. The term 'nature' is key in this context: according to Dorst et al. (2019) one of the principles of NBS is that "*nature, as the concept's central foundation, may take many forms*". Indeed, the understanding of what constitutes 'nature' has caused disagreements and intense scholarly debates, especially in the field of political ecology (Robbins, 2012; Kotsila et al., 2020). Consequently, this makes it challenging to define what can be understood as 'nature' within the scope of NBS (Carsten et al., 2017). In this sense, our results suggest that 'nature' is often understood as - what we would call - the '**green factor**', defined here as the **presence of vegetation.** This is indirectly sustained by the IUCN definition, in which NBS are expected to provide biodiversity benefits (Cohen-Shacham et al., 2016). The '**green factor**' plays an important role when deciding if a certain solution is a Nature-Based one or not. For example, participants (workshops and survey) often associated "being inspired in nature" with the replication of natural processes, as sustained by European Commision (2015) definition. Yet, this was a necessary but not sufficient condition to consider a particular item a NBS: the item in question also had to **employ nature**. For instance, "porous asphalt", replicates natural process of water infiltration, yet it does not necessitate the presence of the 'green factor'.

Another example emphasising the relevance of the 'green factor' is that all NBS units included some form of vegetation, while approximately 70% of them mentioned green-related terms in their names (e.g. "green", "vegetated", "garden", "forest"). This trend could be interpreted almost as an unquestionable, unconscious frame: in order to count as an NBS unit, a solution must be green. In the specialized literature, NBS are often related to expressions such as "greening of cities" (Tozer et al., 2020), "urban green space" (Panno et al., 2017), "urban

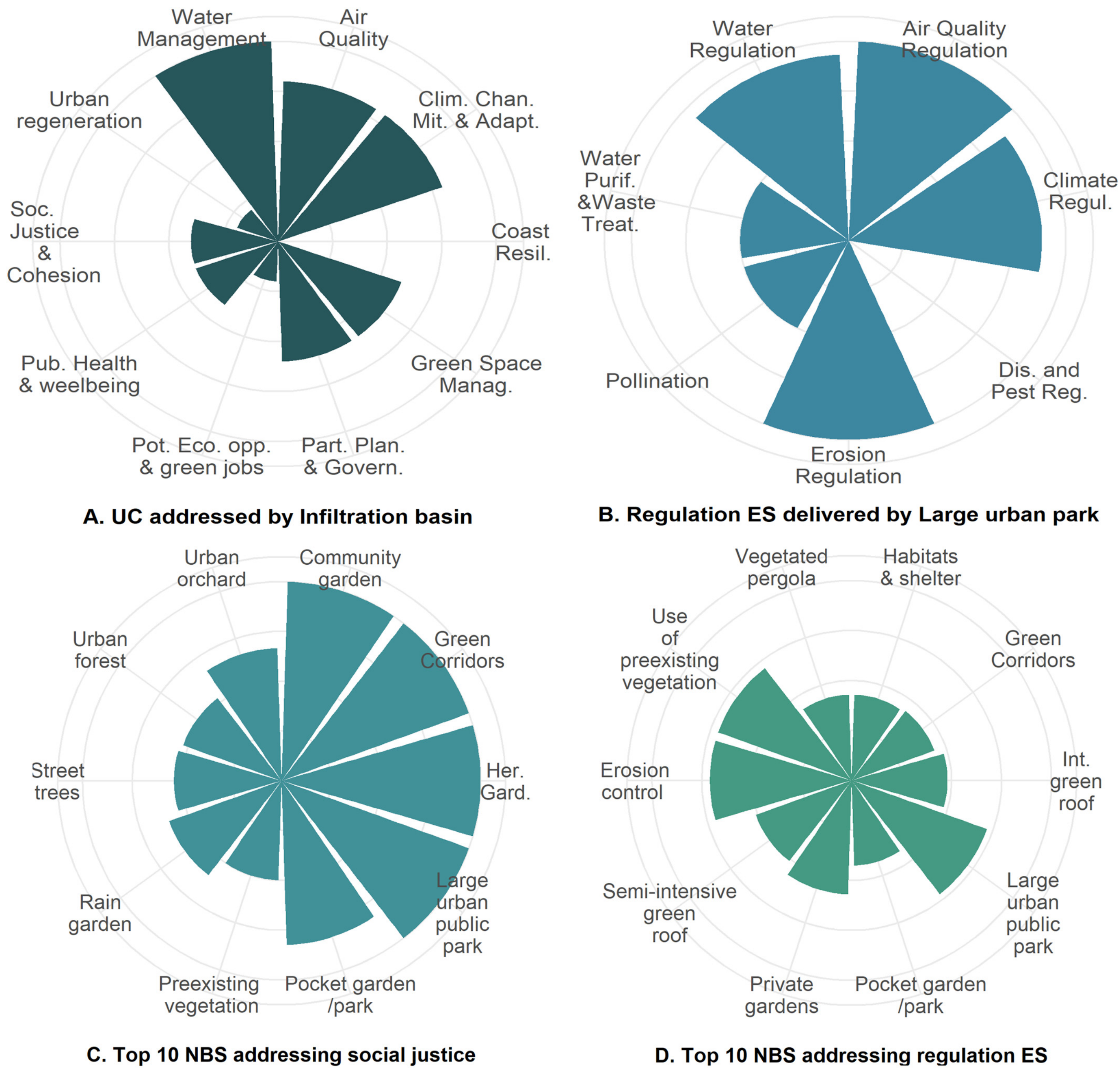

Fig. 3. Example of plots visualized in the tool.

greening" (Dorst et al., 2019; Escobedo et al., 2018), "greening strategy" (Fastenrath et al., 2020) and "green placemaking" (Gulsrud et al., 2018). This frame can be explained by the need to distinguish the natural foundation of NBS in comparison to other conventional grey infrastructure. Moreover, there are current efforts to make cities 'greener'. According to Kotsila et al. (2020) "*in Europe, specifically, NBS are seen not only as an alternative means to address social needs and enhance natural environments but also as a way of* ***boosting green innovation*** *and resilience in cities*".

Apart from the replication and employment of 'nature', other criteria emerging from the participative process were the following: 1) an NBS should be **non-intensive** (in terms of resources) (European Commision, 2015; Faivre et al., 2017) and 2) and NBS should **occur in nature** (Frantzeskaki, 2019)**.** Based on this, items like "Smart soil production in climate-smart urban farming precinct" and "Small-scale urban livestock" have not been considered NBS: the former is not found in nature and the latter can involve intensive use of resources.

It is important to note that by requiring the fulfillment of the factor 'green' for an element to be considered as NBS, we eliminate a whole range of elements based on (bio)filtration through natural porous material. A good example of this is an infiltration trench commonly used for sustainable urban drainage. The role of natural, non-intensive processes (filtration and/or biofiltration) is evident, yet the requirement for 'greening' is not fulfilled.

Moving forward, our results also reveal a resistance to accepting planning/management approaches as NBS. Also, while there was a clear consensus among participants about not including these items, they did not convey a clear justification for this. Yet, the literature validates the criteria of the participants: planning/management approaches belong to the types 1 and 2 of Eggermont et al. (2015), which according

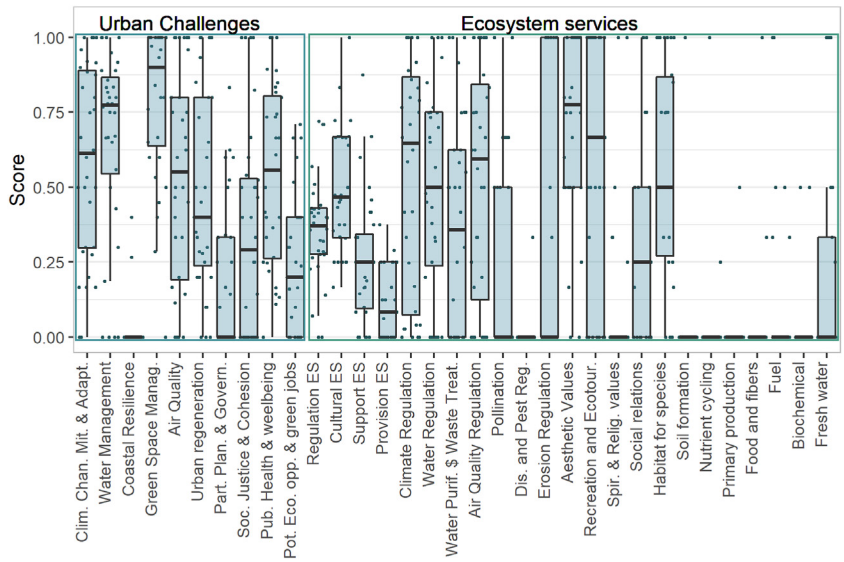

Fig. 4. NBS crossed scores on urban challenges and on ecosystem services.

to Sarabi et al. (2019) were rarely recognized as NBS. Moreover, according to Almenar et al. (2021), there is currently a demand to bring palpable natural structures back to the cities, because they are perceived as more effective than the solutions focused on managing and restoring. Thus, it should not come as a surprise that consulted experts are more inclined to associate NBS with tangible structures rather than more abstract concepts such as management and planning approaches. Nevertheless, we suggest to consider such planning and management aproaches as supportive actions or elements, mainly due to their great relevance regarding the preservation/maintenance of natural capital in cities and implementation and monitoring of NBS.

4.2. The path to NBS standardization

Recently the IUCN released the “Global Standard for Nature-based Solutions”, focused on design and upscaling (IUCN, 2020). This is much-needed progress in terms of facilitating NBS implementation and mainstreaming. Nevertheless, it is equally important to couple these standards with a common set of NBS based on a formalized terminology. In this sense, our list represents an advancement in comparison to the lists provided by the 4 analyzed H2020 projects for two reasons. Firstly, it identifies similar NBS among 4 different European projects, which constitute a ‘core’ set of NBS across all projects. Secondly, it relies on the opinion of worldwide experts within and beyond the EU (e.g. H2020 projects, COST Action "Circular City" or OPPLA community) regarding what an NBS is and how to name it. This presented NBS list is, therefore, an important step towards NBS standardization and it has the potential to evolve in time, with future advances of NBS concept.

Another key advancement of this research is the proposal of a novel NBS classification scheme. Each of the projects analyzed here presented different classifications. Some of the categories proposed in these projects were too broad and thus some NBS could fit in more than one category. For example, the UNL category “greening interventions” – which, strangely, only includes interventions containing trees as the main element - clearly overlaps with other categories such as “vertical greening” and “public green space”. In turn, GU properly differentiates the “arboreal interventions” from other types of greening interventions, even though it includes categories such as “carbon capture” with only one item: planting trees for carbon sequestration. Moreover, the categories proposed by TN provide no clear guidance, apart from the name of the

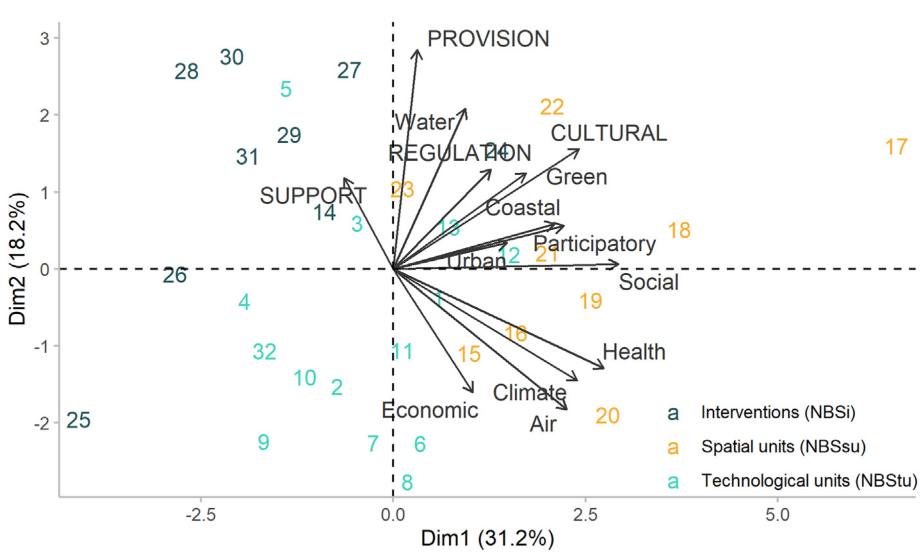

Fig. 5. Principal Component Analysis of the considered NBS, ordinated as a function of their scores on urban challenges (lower-case) and ecosystem services (upper-case), and colored as a function of the hierarchical classification.

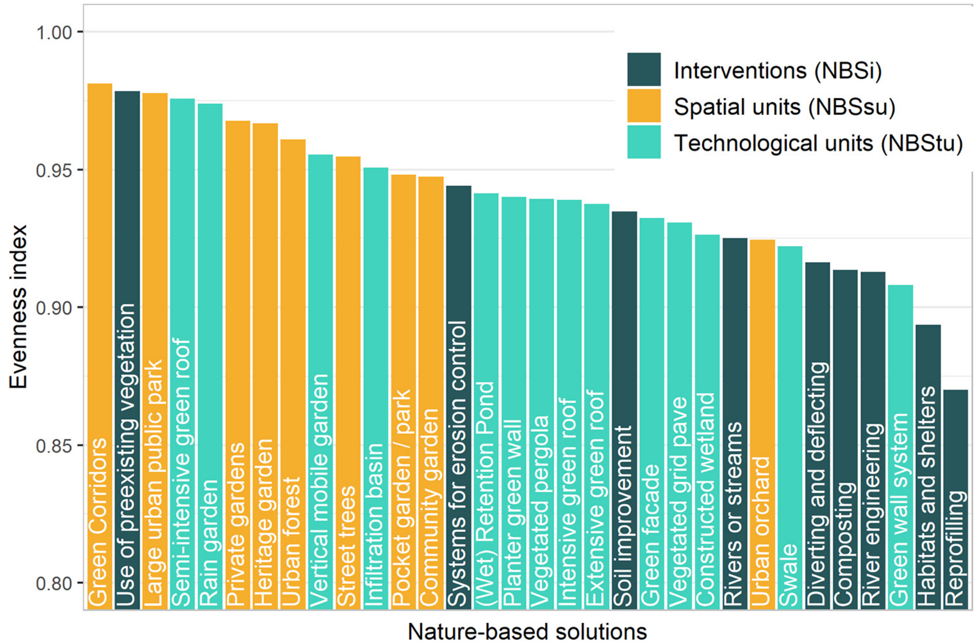

Fig. 6. Evenness index for the considered NBS, colored as a function of the second level of the hierarchical classification.

category itself and the conceptual definition it entails. N4C represents a step forward with respect to the previous classifications since it develops a comprehensive hierarchical classification with more than 20 categories. However, some inconsistencies were identified. For example, some NBS such as "Green walls" and "Vegetated pergola", included in the building category, can be also applied in other sites not strictly related to a building surface (e.g self-standing structures or self-standing walls). In addition, some NBS included in the category "on building & structures", such as green roofs and green walls, could be also included in the category "Water" since they can be designed for water retention and treatment. While these classifications are valuable in terms of putting much needed order in a burgeoning field, we believe there is room for a more accessible, user-friendly and all together simpler way to classify NBS. Therefore, to bridge these gaps, we propose a more compact hierarchical classification, with only 11 categories which are conceptually fine-tuned. Additionally, simple questions support the classification into these categories, which are meant to guide practitioners to select the most suitable NBS according to their needs or to further develop the classification by either, including other NBS in our classification scheme or creating new categories.

Regarding the terminology proposed in this article, this research offers important insights about how people perceived NBS trough the way they name it. In this sense, the names of NBS_{su} contained terms referring to its location, scale/size, ownership and type of structure (e.g. **street** trees, **large or pocket** parks, **private or community** gardens). Almost all names of NBS_{tu} also included terms related to the type of structure to be greened (e.g. green **wall** system, green **roof**, vegetated **pergola)**. Some NBS_{tu} contained terms to distinguishing them from existing natural ecosystems (e.g. **constructed** wetlands), to highlight the process occurring (e.g. **infiltration** basin, (wet) r**etention** Pond) or to characterize design requirements (e.g. **intensive, extensive** and **semi-intensive** green roofs). In contrast, the names of NBS_i, in general, included verbs referring to the actions to be applied, fact which helps to dicern the NBS_i from existing ecosystems and other NBS_i applied in the same context or with similar purposes (e.g. re-meandering, diverting, reprofiling, composting, create, preserve, use).

Furthermore, even if the majority of NBS were named as a result of the surveys, it is undeniable that there is still a lack of agreement within the NBS community. While the survey participants proposed more than 250 new names, others made mention of the existence of well-established guidelines that included accepted terminologies for several of the NBS listed (http://www.efib.org/; https://boku.ac.at/baunat/iblb; https://www.cirf.org/en/home-9/, Woods-Ballard et al., 2015; (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau FLL, 2002); University of Arkansas community design center, 2010). This contradiction can be explained by the fact that terminologies are formulated under social, ethnic and cognitive criteria in which communication among experts and specialists can produce different terms for the same concept and more than one concept for the same term (Faber and Lopez-Rodríguez, 2012). Therefore, as concepts and terms tend to evolve over time, we consider that the application of cognitive models coupled with the reviewing of existing standards in the field of NBS terminology could be helpful to validate the terminologies proposed in this article.

4.3. Assessment for urban challenges and ecosystem services

Integrating qualitative assessments from different projects puts forward an overview of how the European NBS community (experts, urban planners and other practitioners) evaluates the performance of NBS in addressing UC and ES. Our results indicate that the impact of NBS on environmental challenges such as "Climate mitigation and adaptation" ($M_e = 0.61$), "Water management" ($M_e = 0.77$) and "green space management" ($M_e = 0.90$) might be perceived as more relevant than social-economic challenges such as "Participatory planning" ($M_e = 0.0$), "Social justice and cohesion" ($M_e = 0.29$) and "Economic opportunities" (0.20). The same can be seen in terms of "Regulation" ($M_e = 0.37$) and "Cultural services" ($M_e = 0.47$) which received higher average scores than "Supporting services" ($M_e = 0.25$) and "Provisioning services" ($M_e = 0.08$). Except for "Habitat for species" and "Fresh water", all remaining supporting and provisioning services received a score of 0 for more than 90% of NBS. This might suggest that even though NBS are multifunctional, there is a greater agreement regarding the role of NBS in addressing environmental challenges, regulating and cultural services than in what concerns social-economic oriented challenges and supporting and provision services. The disparity is likely not indicative of the NBS potential to address UC or provide ES, but rather reflective of uneven efforts in the scientific community in evaluating NBS impacts on said challenges and services. In this sense, the review performed by Almenar et al., 2021 reveals that the great majority of scientific articles are dealing with NBS related to water management and climate change, while only very few papers address social challenges such as public participation and governance.

Regarding the multivariate analysis, the PCA and the evenness index showed that NBS_{su} are providing more co-benefits than NBS_{tu} and NBS_{i}. This may be because NBS_{su} have been more explored by researchers than other typologies and, consequently, the co-benefits are better documented (Almenar et al., 2021). Nonetheless, there are two important insights of the multivariate analysis: (1) there is no overlap in the final list of NBS in terms of UC and ES, that is, each NBS in the list is useful for different situations, and (2) the classification of NBS, despite being designed in terms of visual and functional aspects, works well in terms of addressed UC and delivered ES. This shows the robustness of the proposed classification scheme.

All explored projects edited NBS catalogues in static format (such as pdf documents). In addition, others like N4C or GU presented more dynamic tools to support decision making such as the the "Nature Based Solutions explorer" of N4C (https://nbs-explorer.nature4cities-platform.eu/) and the *NBS selection tool* of GU (https://www.urbangreenup.eu/resources/nbs-selection-tool/nbs-selection-tool.kl). However, as far as we know, there is no tool quantitatively evaluating the performance of NBS both in terms of addressing UC and delivering ES. The tool presented in this article (https://icra.shinyapps.io/nbs-list) provides the scores of each NBS in terms of UC, ES and the subsequent categories. More precisely, it provides the scores visualization of a specific NBS (Fig. 3A and B), along with its description, as well as the visualization of different NBS' scores regarding an individual UC or ES (Fig. 3C and D). This allows experts and practitioners to explore the co-benefits of any NBS or identify the NBS that best addresses a specific issue.

5. Conclusions

There is still a long way to reduce the existing gap between NBS technological development (scientific community), practical and cost-effective applications (public-private sectors) and existing values of the civil society. It is not an easy gap to address, especially when there is no common agreement on the NBS conceptualization. In this sense, our research represents the perspectives of a wide and diverse NBS community and thus contributes to set a path towards common understanding of the NBS concept.

This article proposes a replicable methodology which delivers a set of 32 NBS fully evaluated in terms of UC and ES and a novel classification scheme, robust enough for systematic knowledge representation and open for further expansion. Such efforts can enable further integration of databases beyond the scope of the four H2020 projects analysed here. Moreover, the proposed classification scheme represents a step forward in the conceptualization of NBS: they are no longer seen as sole elements but as part of large ensembles, forming complex "living" systems (e.g. NBS combined with other NBS or grey infrastructure or conventional technologies). In this sense, we believe that NBS can gain from a more holistic perspective, in which their interactions with other solutions (Nature-Based or not) can help diversify the provision of ES, close the resources loops, and compensate possible disservices.

The results indicate that the 'green factor' and non-intensive (in terms of resource use) solutions occurring in nature are key aspects for practitioners to identify a particular solution as an NBS. Such insights can facilitate the improvement of existing NBS definitions towards clearer and, at the same time, more comprehensive ones. However, more research coupling cognitive analysis with other qualitative methods could shed light on why people tend to privilege certain terms over others when naming NBS. Such mixed quantitative-qualitative approaches can also provide a better understanding of 'nature' as an 'empty signifier' - e.g. a term that can display a set of different, sometimes even opposing meanings (Brown, 2015) in the scope of NBS, thus engaging with current debates in political ecology on the matter.

The common NBS list, terminology and classification scheme proposed in this article are not definitive but intended to evolve in time, along with relevant advancements in the NBS field. Further research is needed in order to discern between NBS interventions – as defined in our classification - and other green planning/management approaches. It is important to better understand, for instance, why practitioners excluded many of the latter. Moreover, it is important to consider, if these items had been considered, what would this have entailed for the current overall conceptualization and classification. Indeed, some of the excluded NBS can be further reviewed (especially those excluded for not having a performance assessment of UC and ES or those that were not found in more than one project).

The overall results of the integrative assessment suggest a need to enhance scientific efforts in evaluating NBS performance in terms of socio-economic challenges, supporting and provisioning services, especially in the case of technological and interventional NBS.

All in all, this article defends that NBS community (research, public and private sector) needs to speak the same "Nature-based" language in order to further facilitate the knowledge transfer, replication and the engagement of civil society and thus promote a real change in the way citizens perceive the relevance of NBS for making their cities more resilient.

CRediT authorship contribution statement

J.A.C. Castellar: Conceptualization, Methodology, Formal analysis, Investigation, Project administration, Supervision, Visualization, Writing – original draft, Writing – review & editing. **L.A. Popartan:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **J. Pueyo-Ros:** Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **N. Atanasova:** Methodology, Funding acquisition, Supervision, Investigation, Writing – original draft, Writing – review & editing. **G. Langergraber:** Methodology, Funding acquisition, Investigation, Supervision, Writing – original draft, Writing – review & editing. **I. Säumel:** Funding acquisition, Writing – review & editing. **L. Corominas:** Supervision, Funding acquisition, Writing – original draft, Writing – review & editing. **J. Comas:** Funding acquisition, Conceptualization, Project administration, Supervision, Writing – original draft, Writing – review & editing. **V. Acuña:** Funding acquisition, Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, 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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2021.146237.

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