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# H2020 projects and EU research needs for Nature-Based adaptation Solutions

## Abstract

This paper investigates the documentation produced by 21 Horizon 2020 (H2020) projects for the use of Nature Based Solutions (NBS) for climate change adaptation (NBaS). Accordingly, an updated state-of-the-art on current knowledge and its limits is presented. Findings are then capitalized on for highlighting research needs. The main objective of this study is to inform future orientations on NBaS research. Accordingly, it can be considered as an effort to complement the 2021 European strategy for climate change adaptation, under which NBaS is listed as one of the three cross-cutting priorities. The obtained results reflect actual outcomes from completed projects, while ongoing projects provided a substantial amount of relevant knowledge. From the exhaustive knowledge-research need inventory, one of the most significant identified gaps was the need for developing further the fundamental scientific basis behind these solutions, as the concept favors its practical nature and places less emphasis on its scientific counterpart.

**Keywords:** nature-based solutions, adaptation, NBaS, Horizon 2020

## 1. Introduction

The apex position of Climate Change Adaptation (CCA) and Nature-Based Solutions (NBS) in European priority agendas underlines the importance of these concepts for Europe. CCA has been a central interest for the EU since 2013 with the EU Adaptation Strategy (European Commission, 2013), while NBS as a concept, was coined at the European level. NBS are solutions that make use of ecosystems for responding to societal challenges (IUCN French Committee, 2016). First mentions of the concept (in strict terms) appeared in 2008 by the World Bank (Hanson et al., 2020). Since then, the concept has increasingly expanded and has attracted considerable scientific attention (Castellanos et al. 2020).

The European Commission (2015) defines NBS as: *“Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions”*. NBS are particularly sought for their capacity to balance trade-offs between ecosystemic conservation, social needs and economic growth (Al Sayah et al., 2021). Cohen-Shacham et al. (2016) consider NBS as an umbrella concept that includes: (i) ecosystem restoration approaches (e.g. ecological restoration and engineering); (ii) issue-specific ecosystem-related approaches (e.g. ecosystem-based adaptation/mitigation, climate adaptation services and ecosystem-based disaster risk reduction); (iii) infrastructure-related approaches (e.g. natural and green infrastructure); (iv) ecosystem-based management approaches (e.g. integrated water resources and coastal zone management); and (v) ecosystem protection approaches (e.g. area-based conservation such as protected area management). Examples of NBS applications are quite common around the world and range from minimal interventions (Type 1 NBS), to minor ecosystem management approaches (Type 2 NBS), and extensive management/creation of ecosystems (Type 3) (Eggermont et al., 2015). Examples of minimal interventions are protected areas such as the Wet Tropics World Heritage Area of Australia, where wetlands and mangroves are used for reducing the risks of cyclones and coastal hazards (IUCN, 2014). Agroecology and agroforestry are considered as applications of regulated management approaches (Hotelier-Rous et al., 2020), while green roofs [ref. Versini et al. (2015)] are examples of extensive ecosystem management/creation.

From the European Commission’s definition, the belief of Europe that long-term economic competitiveness and security depend on the sustainable use of natural resources is apparent, hence its interest in NBS (Maes and Jacobs, 2017). Nonetheless, climate change is one of the major hurdles that are preventing a smooth transition towards Europe’s above-mentioned belief (Castellanos et al., 2020). For this purpose, Europe has set a path to harness the potential of NBS for CCA (Li et al., 2021). The occurrence of the term “adaptation” within the EU’s definition of NBS, in the seventh criterion for NBS of the International Union for

47 Conservation of Nature (IUCN), and as one of the seven societal challenges NBS respond to strongly  
48 emphasized the NBS-CCA nexus (IUCN, 2020). The seventh IUCN criteria “NBS are managed adaptively,  
49 based on evidence” takes part of eight criteria set by the IUCN (2020) for a solution to be considered as a  
50 NBS [refer to IUCN (2020) for more details]. The seven above-mentioned challenges are climate change  
51 mitigation and adaptation, disaster risk reduction, economic and social development, human health, food  
52 security, water security and environmental degradation/biodiversity loss (IUCN, 2020).

53 In this vein, NBS for climate change adaptation (henceforth referred to as Nature-Based adaptation  
54 Solutions NBaS) have gained prominence both in scientific literature (IUCN French Committee, 2019) and  
55 in practical applications, particularly in Europe (Seddon et al., 2019). More recently, NBaS were defined  
56 as one of the three cross-cutting priorities in the EU’s 2021 strategy on CCA (European Commission,  
57 2021a). Accordingly, the strong NBaS background of Europe is pivotal to exploit for studying the evolution  
58 of these solutions. At the French scale, NBaS are trusted to be the way forward for leveraging the second  
59 national climate change adaptation plan. It is under this context that the LIFE ARTISAN (Achieving  
60 Resiliency by Triggering Implementation of nature-based Solutions for climate Adaptation at a National  
61 scale) project aims to promote the implementation of NBaS throughout the French (metropolitan and  
62 overseas) territory ([www.life-artisan.fr](http://www.life-artisan.fr)).

63 With a favorable political context and a very receptive social fabric (Maes and Jacobs, 2017), the European  
64 Commission (EC) placed significant efforts to deepen knowledge on NBS-NBaS. Perhaps one of the most  
65 ample translations of this interest is the integration of NBS into the Horizon 2020 R&I (H2020) program.  
66 Accordingly, the latter is one of the most suitable platforms to explore as it reflects the role of the EC in  
67 research and innovation on NBS, in the allocation of funds for NBS, and in the production of tools,  
68 databases and scientific contributions. Knowing that NBS and NBaS are based on ecosystems and their  
69 services (Potschin et al., 2016), the interest of the EU in the latter increased even more after the COVID-  
70 19 pandemic. Accordingly, the EU is one of several parties developing programs that integrate natural  
71 solutions (thereby NBS) into post-COVID plans as nature-positive stimulus packages (Armstrong, 2021;  
72 GEF Secretariat, 2020). On a global scale, the EU’s post-COVID19 recovery package is the most eco-  
73 friendly, with 37 per cent of the planned 750 billion euros directed towards green initiatives (Bayat-Renoux  
74 et al., 2020). To this end, the EU is planning for an ambitious 2030 biodiversity strategy that aims to  
75 transform minimum 30 percent of Europe’s lands and sea into protected areas (even partially) to ensure  
76 healthy societies via healthy ecosystems (GEF Secretariat, 2020).

77 Despite the strong momentum behind the concept and the high expectations, NBaS are not as simple as  
78 expected. Since they encompass both CCA and NBS, NBaS inherently carry the difficulties and  
79 complexities of both their components. In terms of CCA, the composite nature of climate change and its  
80 uncertainties are particularly relevant (UNFCCC, 2020). In this vein, the absence of decisive measurable  
81 metrics, thresholds, and proof of risk reduction at both the short (i.e. pre-2050) and long-terms (i.e. post-  
82 2050 and climatic cycle scale) are major hurdles to overcome (UNEP, 2021). Even if the mentioned  
83 challenges are surpassed, the difficulty of understanding how adaptation functions and what its implications  
84 for resilience are still persists (IUCN, 2010). In terms of NBS, inconclusive evidence on their performance  
85 (Chausson et al., 2020), the uncertain behavior of ecosystems and their components under changing  
86 climates (Weiskopf et al., 2020), the questionable quantification of tipping points and thresholds (Groffman  
87 et al., 2006), the inconsideration of trade-offs between benefits (Seddon et al., 2020) and difficulties of  
88 upscaling (Al Sayah et al., 2021) are major gaps to bridge. Overlooking the above-mentioned challenges  
89 can lead to biased designs, conceptualization and implementation of NBaS. This in turn compounds the  
90 risks of maladaptation and multiplies the risks of disservices (Wickenberg et al., 2021). Other barriers such  
91 as public acceptance, stakeholder participation, governance obstacles and funds (Al Sayah et al., 2021) are  
92 also prevalent and can be considered as additional limiting factors.

93 While certainly win-win solutions, both NBS and NBaS are often portrayed as immune systems capable of  
94 resolving the challenges they were introduced to face. In this sense, a great deal of importance is given to

95 the benefits derived from these solutions, particularly for human health and socioeconomic returns.  
96 Although this representation might be favorable for increasing the public/political acceptance of these  
97 solutions, it also widens the gap between the research community and practitioners by creating “language  
98 barriers” as highlighted by the REGREEN project (Banzhaf et al., 2020). These barriers are mainly due to  
99 the multitude of disciplines implicated in the design and implementation of these solutions. Therefore, for  
100 properly unlocking the potential of these solutions, research are required to overcome the current paradigm  
101 (Wickenberg et al., 2021), and develop further the science behind these solutions.

102 On the basis of what was presented, this study aims to compile an inventory of knowledge on NBaS with a  
103 focus on European efforts through the H2020 program. To do so, the study first explores current advances  
104 on NBaS from relevant projects, extracts identified limits and ultimately proposes lines of work to develop.  
105 The rationale behind this approach is that by providing a scientific meta-analysis, an overview of the EU’s  
106 progress is offered (Davies et al., 2021). Accordingly, the objectives of this paper are: (1) to study the  
107 transition from NBS to NBaS in Europe (without narrowing the NBS concept to climate change adaptation  
108 only); (2) unravel current and emerging research trends for NBaS; (3) providing a state-of-the-art on  
109 currently established NBaS knowledge and limits and (4) reviewing existing research gaps and proposing  
110 lines of work to develop. At no point do the Authors undermine the importance of the societal, political and  
111 governance domains of the concept. For fully unlocking knowledge on NBS-NBaS, the integration of these  
112 angles is a must. However, this was beyond the scope of this review that solely focuses on the more  
113 biophysical angles of the concept.

## 114 2. Materials and methods

115 The workflow of this study consisted of a three-phased approach: search, filter, and extract/analyze. For the  
116 Search phase, the European Commission’s Community Research and Development Information Service  
117 (CORDIS) website [<https://cordis.europa.eu/>] was used to identify the relevant projects. The search query  
118 consisted of “nature-based solutions” as a keyword. The “program” and “collections” filters were used to  
119 refine the search. Under the “program” filter, the H2020 box was selected, while the project box was  
120 selected under “collection”. The chosen date range was from 2014 onwards, as the latter marks the start of  
121 the H2020 program. Within this interval, the year 2015 is one of the most important NBS landmarks in  
122 Europe: the official integration of NBS into the EU’s agenda (European Commission, 2015)

123 a) The first search (*search 1*) yielded NBS H2020 projects. The selected projects were then validated against  
124 the Oppla database, and two EC-issued reports Wild et al. (2020) and Dumitru and Wendling (2021). The  
125 first presents an analysis of EU-funded projects, while the second is the EC’s most recent handbook for  
126 evaluating the impact of NBS. As a first result, 41 projects were found. Given the scope of the study (i.e.  
127 NBaS), a second refinement step was performed (*search 2*). The aim of search 2 was to zero in on strictly  
128 NBaS related projects. For that purpose, each CORDIS webpage was revisited to determine under which  
129 topic and program is the project listed. To this end, projects with the following topics were selected:

- 130 • SC5-10-2016 - Multi-stakeholder dialogue platform to promote innovation with nature to address  
131 societal challenges.
- 132 • SCC-02-2016-2017 - Demonstrating innovative nature-based solutions in cities.
- 133 • SC5-09-2016 - Operationalizing insurance value of ecosystems.
- 134 • SCC-03-2016 - New governance, business, financing models and economic impact assessment  
135 tools for sustainable cities with nature-based solutions (urban re-naturing).
- 136 • SC5-08-2017 - Large-scale demonstrators on nature-based solutions for hydro-meteorological  
137 risk reduction.
- 138 • SC5-13-2018-2019 - Strengthening international cooperation on sustainable urbanization: nature-  
139 based solutions for restoration and rehabilitation of urban ecosystems.
- 140 • LC-CLA-06-2019 - Inter-relations between climate change, biodiversity and ecosystem services.
- 141 • SC5-14-2019 - Visionary and integrated solutions to improve well-being and health in cities.

142 For further validation, the program heading in each project’s CORDIS webpage was also examined for  
143 inclusion. Accordingly, the following programs were of interest:

- 144 • H2020-EU.3.5.1. - Fighting and adapting to climate change.
- 145 • H2020-EU.3.5.1.2 - Assess impacts, vulnerabilities and develop innovative cost-effective  
146 adaptation and risk prevention and management measures.
- 147 • H2020-EU.3.5.2.1. - Further our understanding of biodiversity and the functioning of ecosystems,  
148 their interactions with social systems and their role in sustaining the economy and human well-  
149 being.

150 To make sure that no project was left out, each project’s website was then revisited. Accordingly, any  
151 elements related to the scope of the study in the project’s impacts, description or objectives were considered  
152 as additional inclusion factors. Following *Search 2*, a total of 27 NBaS projects were retained. Each  
153 project’s deliverables were then obtained from the CORDIS results tab as well as the project’s webpage.  
154 This step was performed since some deliverables are not yet listed on CORDIS despite their existence on  
155 the projects’ webpages.

156 b) The filtering phase consisted of two steps. The first was a general approach where deliverables  
157 were retained based on their titles, general content and relevant sections. At this stage it is important  
158 to mention several elements: (1) textual material was compiled and collected during the January-  
159 July 2021 period. Therefore, any outcome following this period is not included. (2) At the time of  
160 this study several projects were still ongoing while others have only begun in 2020. Some were  
161 affected by the COVID-19 pandemic while others were still in their pre-results phases.  
162 Consequently, some projects had no deliverables during the study period. (3) Some projects had  
163 no/restricted access to deliverables and hence were unavailable. In order to account for these  
164 shortcomings, the results packages on the related CORDIS webpage and scientific publications  
165 (articles) issued from these projects were included where applicable. The inclusion of scientific  
166 articles where applicable also contributed to the solidification and the enrichment of the study’s  
167 corpus as these are peer-reviewed by scientific experts. Projects from which scientific articles were  
168 added are: ThinkNature, CLEVER Cities, Nature4Cities, PHUSICOS, REGREEN, RENATURE,  
169 NATURVATION, Connecting Nature, CLEARING HOUSE, OPERANDUM, NAIAD, DRYvER,  
170 Urban GreenUP, PHUSICOS, and RECONNECT. Accordingly, 21/27 projects with 137 deliverables  
171 were passed to the second filtering phase. The second step was more specific and consisted of  
172 examining the reports individually and entirely through careful reading of each.






















173 c) Finally, findings were extracted during the extract/analyze phase. At no point do the Authors assume that  
174 their findings are not debatable. The Authors acknowledge that some sample-related or selection flaws may  
175 be inherent. However, the best possible measures were taken to avoid any unjustified assumptions and to  
176 ensure a minimal error margin.

### 177 **3. Results and discussions**

178 This section provides a number of results and discussions grouped under different themes. Accordingly, the  
179 first section discusses the way NBaS are addressed in the H2020 projects. The second section discusses the  
180 NBaS terminology in H2020 projects and the NBS-NBaS transition, the third section discusses  
181 geographical distributions and gradients, while the fourth section presents the target ecosystems and their  
182 challenges. The fifth section details current knowledge and limitations per ecosystem, while the sixth  
183 presents the same pattern per main research topics. Further details can be found under each throughout the  
184 different sub-sections.

#### 185 **3.1. General presentation of the studied projects**

186 The retained projects are of different backgrounds and encompass several objectives for the use of NBS-  
 187 NBaS (Figure 1).

H2020 NBaS projects		Ecosystem services			
Name	Ecosystem	Provision	Regulation	Support	Cultural
	Freshwater	•		•	•
	Marine and coastal	•	•	•	
	Mountainous	•	•	•	
	All	•	•	•	
	All	•	•	•	•
	All	•	•	•	•
	All	•	•	•	•
	Urban	•	•	•	•
	Urban	•	•	•	•
	Urban	•		•	•
	Urban	•	•	•	•
	Urban	•	•	•	•
	Urban	•	•	•	•
	Urban	•	•	•	•
	Urban		•		•
	Urban	•	•	•	•
	Urban	•	•	•	•
	Urban		•	•	•
	Urban		•	•	•
	Urban	•	•	•	•
	Urban		•	•	•

188

189 *Figure 1: A representation of retained projects and the ecosystem services these target (colors refer to ecosystems)*

190 Only those with deliverables, i.e. 21 NBaS H2020 projects, will be detailed from this point onwards. The  
 191 list of retained projects is as follows: CLEARING HOUSE, CLEVER Cities, Connecting Nature, DRYvER,  
 192 EdiCitNet, EuPOLIS, FutureMARES, GrowGreen, NAIAD, Nature4Cities, NATURVATION,  
 193 OPERADNUM, PHUSICOS, proGReg, RECONNECT, REGREEN, RENATURE, ThinkNature, UNaLab,  
 194 Urban GreenUP and URBiNAT. Table 1 provides each project’s CORDIS/website access links, topic and  
 195 number of retained deliverables.

196 *Table 1: The inventory of retained H2020 NBaS projects and their retained deliverables*

Project name	CORDIS page	Website	Topic	Action	Retained deliverables
CLEARING HOUSE	<a href="https://cordis.europa.eu/project/id/821242">https://cordis.europa.eu/project/id/821242</a>	<a href="http://clearinghouseproject.eu/">http://clearinghouseproject.eu/</a>	SC5-13-2018-2019	Research and Innovation action	2



CLEVER Cities	<a href="https://cordis.europa.eu/project/id/776604">https://cordis.europa.eu/project/id/776604</a>	<a href="https://clevercities.eu/">https://clevercities.eu/</a>	SCC-02-2016-2017	Innovation action	9
Connecting Nature	<a href="https://cordis.europa.eu/project/id/730222">https://cordis.europa.eu/project/id/730222</a>	<a href="https://connectingnature.eu/">https://connectingnature.eu/</a>	SCC-02-2016-2017	Innovation action	3
DRYvER	<a href="https://cordis.europa.eu/project/id/869226">https://cordis.europa.eu/project/id/869226</a>	<a href="https://www.dryver.eu/results">https://www.dryver.eu/results</a>	LC-CLA-06-2019	Research and Innovation action	1
EdiCitNet	<a href="https://cordis.europa.eu/project/id/776665">https://cordis.europa.eu/project/id/776665</a>	<a href="https://www.edicitnet.com/medi alibrary/deliverables/">https://www.edicitnet.com/medi alibrary/deliverables/</a>	SCC-02-2016-2017	Innovation action	11
EuPOLIS	<a href="https://cordis.europa.eu/project/id/869448">https://cordis.europa.eu/project/id/869448</a>	<a href="http://eupolis-project.eu/">http://eupolis-project.eu/</a>	SC5-14-2019	Innovation action	3
FutureMARES	<a href="https://cordis.europa.eu/project/id/869300">https://cordis.europa.eu/project/id/869300</a>	<a href="https://www.futuremares.eu/">https://www.futuremares.eu/</a>	LC-CLA-06-2019	Research and Innovation action	2
GrowGreen	<a href="https://cordis.europa.eu/project/id/730283">https://cordis.europa.eu/project/id/730283</a>	<a href="http://growgreen-project.eu/">http://growgreen-project.eu/</a>	SCC-02-2016-2017	Innovation action	4
NAIAD	<a href="https://cordis.europa.eu/project/id/730497">https://cordis.europa.eu/project/id/730497</a>	<a href="http://naiad2020.eu/">http://naiad2020.eu/</a>	SC5-09-2016	Research and Innovation action	7
Nature4Cities	<a href="https://cordis.europa.eu/project/id/730468">https://cordis.europa.eu/project/id/730468</a>	<a href="https://www.nature4cities.eu/">https://www.nature4cities.eu/</a>	SCC-03-2016	Research and Innovation action	10
NATURVATION	<a href="https://cordis.europa.eu/project/id/730243">https://cordis.europa.eu/project/id/730243</a>	<a href="https://www.naturvation.eu/">https://www.naturvation.eu/</a>	SCC-03-2016	Research and Innovation action	14
OPERANDUM	<a href="https://cordis.europa.eu/project/id/776848">https://cordis.europa.eu/project/id/776848</a>	<a href="https://www.operandum-project.eu/">https://www.operandum-project.eu/</a>	SC5-08-2017	Innovation action	10
PHUSICOS	<a href="https://cordis.europa.eu/project/id/776681">https://cordis.europa.eu/project/id/776681</a>	<a href="https://phusicos.eu/">https://phusicos.eu/</a>	SC5-08-2017	Innovation action	12
proGReg	<a href="https://cordis.europa.eu/project/id/776528">https://cordis.europa.eu/project/id/776528</a>	<a href="https://progireg.eu/">https://progireg.eu/</a>	SCC-02-2016-2017	Innovation action	5
RECONNECT	<a href="https://cordis.europa.eu/project/id/776866">https://cordis.europa.eu/project/id/776866</a>	<a href="http://www.reconnect.eu/">http://www.reconnect.eu/</a>	SC5-08-2017	Innovation action	9
REGREEN	<a href="https://cordis.europa.eu/project/id/821016">https://cordis.europa.eu/project/id/821016</a>	<a href="https://www.regreen-project.eu/">https://www.regreen-project.eu/</a>	SC5-13-2018-2019	Research and Innovation action	4
RENATURE	<a href="https://cordis.europa.eu/project/id/809988">https://cordis.europa.eu/project/id/809988</a>	<a href="http://renature-project.eu/">http://renature-project.eu/</a>	*	Coordination and support action	7
ThinkNature	<a href="https://cordis.europa.eu/project/id/730338">https://cordis.europa.eu/project/id/730338</a>	<a href="https://www.think-nature.eu/">https://www.think-nature.eu/</a>	SC5-10-2016	Coordination and support action	8
UNaLab	<a href="https://cordis.europa.eu/project/id/730052">https://cordis.europa.eu/project/id/730052</a>	<a href="https://unalab.eu/en">https://unalab.eu/en</a>	SCC-02-2016-2017	Innovation action	6
Urban GreenUP	<a href="https://cordis.europa.eu/project/id/730426">https://cordis.europa.eu/project/id/730426</a>	<a href="https://www.urbangreenup.eu/">https://www.urbangreenup.eu/</a>	SCC-02-2016-2017	Innovation action	9
URBiNAT	<a href="https://cordis.europa.eu/project/id/776783">https://cordis.europa.eu/project/id/776783</a>	<a href="https://urbinat.eu/">https://urbinat.eu/</a>	SCC-02-2016-2017	Innovation action	1

197 \*RENATURE is not attributed to the same topics, but generally it can be listed under several ones.

198 Connecting Nature, GrowGreen, UNaLab and Urban GreenUP utilize NBS for climate and water resilience  
199 in cities. Nature4Cities and NATURVATION investigate governance, business, finance and economic  
200 models and assessment for NBS. The NAIAD project complements the actions mentioned-above by  
201 providing an assessment of the insurance value of ecosystem services. OPERANDUM develops NBS to  
202 mitigate hydro-meteorological phenomena, URBiNAT focuses on regenerating and integrating deprived  
203 urban contexts through NBS, proGReg harnesses the power of nature for urban regeneration, while  
204 RECONNECT aims to reconcile Europe with its citizens through democracy and the rule of law. PHUSICOS  
205 will demonstrate how NBS can reduce risks in mountain landscapes in one the very few H2020 mountain

206 related projects. ThinkNature aims to develop a communication platform to connect various stakeholders  
207 and to support the understanding and promotion of NBS at different geographical levels. RENATURE  
208 builds a strategy and research cluster targeting NBS for sustainable development through scientific  
209 excellence and innovation. EdiCitNet aims to explore the potential of Edible City Solutions in cities to  
210 increase social cohesion, equality, food security and adapt these solutions to the urban realm. CLEVER  
211 Cities targets urban regeneration (social, environmental and economic improvements) through NBS.  
212 CLEARING HOUSE aims to mobilize urban forest-based solutions for rehabilitating, restoring and  
213 reconnecting urban settings. REGREEN aims to generate evidence on the integration of ecosystem services  
214 and biodiversity into NBS and to advocate the latter for urban planning. FutureMARES aims to provide  
215 NBS for CCA and Climate Change Mitigation (CCM) in marine environments around Europe. EuPOLIS  
216 aims to utilize natural systems (NBS) to enhance public health and well-being and create resilient urban  
217 ecosystems. DRYvER aims to established strategies for the mitigation and adaptation to climate change  
218 effects in dry river networks through the integration of hydrological and ecological (NBS) perspectives  
219 among other factors.

220 As can be noticed, the projects cover a range of different backgrounds, and possess objectives that do not  
221 cover the same scopes. The different nature, scales, data, objectives and methods of the projects make  
222 drawing parallel between them difficult. However, it is possible to draw on similar lines of work and  
223 research needs.

### 224 **3.2. On the NBS-NBaS terminology, concept and transitions**

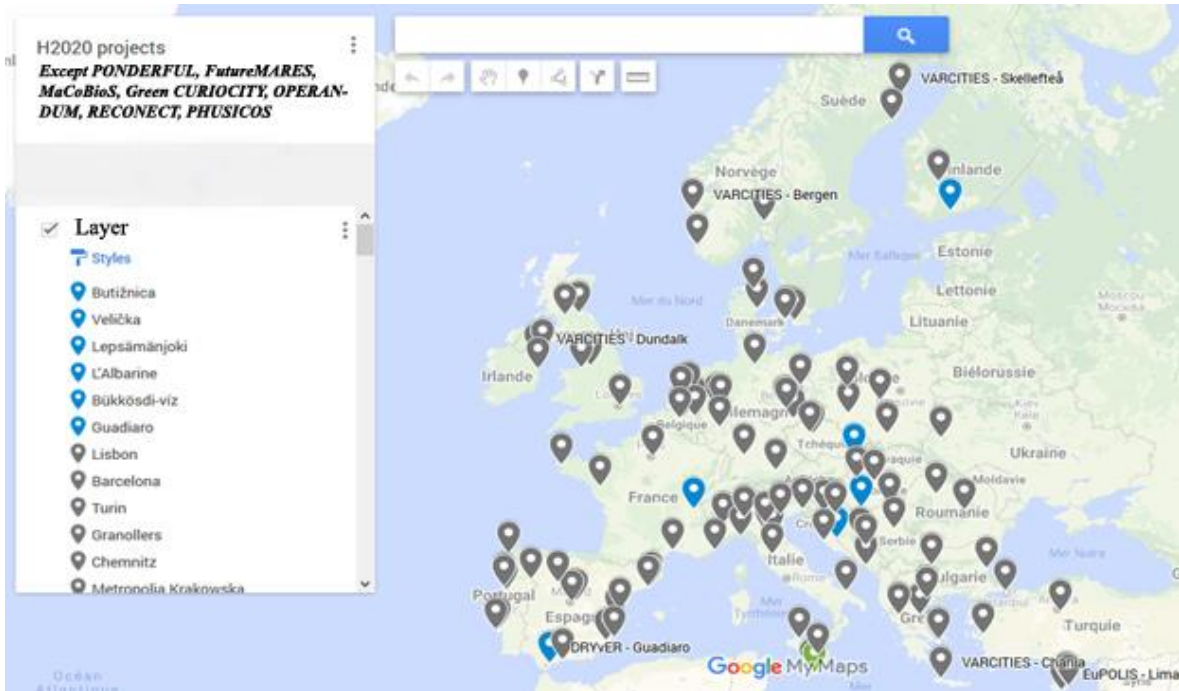
225 In terms of definitions, some projects adopt the EC's definition, others compare between the EC's and the  
226 IUCN's definitions (Cohen-Shacham et al., 2016), while many reformulate their own definition of the  
227 concept. This discrepancy may reflect the various foci or interpretations. However, it can also indicate that  
228 the scientific progress behind the concept has not been fully transposed into the policy and management  
229 angles (Grace et al., 2021). Two remarkable and important insights from H2020 projects stand out: 1) some  
230 Authors believe that NBS are sometimes oversold (discussion in section 5.2.), and 2) others do not favor  
231 the term NBS in the first place. In this context, Bailly et al. (2019a) state the following: "*NBS is a recent  
232 European expression that is inappropriate. Experts and researcher prefer the term Nature. NBS can be  
233 interesting to refer to the ecosystem services of nature, but tends to reduce nature to its utility without  
234 considering the others dimensions that surround it.*"

235 Throughout the projects, the transition from NBS to NBaS can be considered as progressively ongoing.  
236 This transition was noticed within the individual projects, but can also be attributed to a stronger emphasis  
237 on climate change adaptation within the NBS framework. It is safe to assume that this transition is a subject  
238 of study in Europe (since 2014 at least), and that several projects tend to extend their knowledge to extra-  
239 European contexts (namely in Asia and Latin South America). Clearly, the root causes of this ongoing  
240 transition and its future trajectory are interesting elements to study. However, such an analysis will require  
241 time to become fully possible.

### 242 **3.3. Geographical distribution and analysis**

243 The geographical distribution is presented in Figure 2. Several large scale projects such as full mountain  
244 ranges, the EU scale or the EU's coastal environments are not represented in Figure 2 for display purposes  
245 only. This is the case of the PONDERFUL, FutureMARES, MaCoBioS, Green CURIOCITY,  
246 OPERANDUM, RECONNECT, PHUSICOS and NAIAD sites. However, these were not excluded from the  
247 analysis phase.

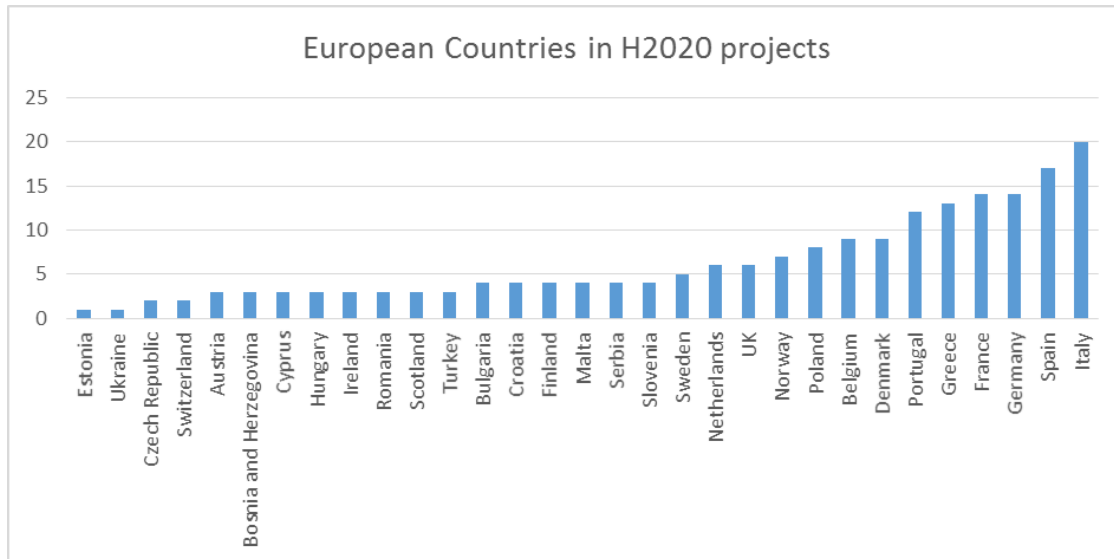




248  
 249 *Figure 2: The geographical distribution of the retained projects' intervention sites, link to Google map:*  
 250 [https://www.google.com/maps/d/u/1/edit?mid=1OScN37smu3dWN9w1\\_W2gHDDP3HwNySP4&usp=sharing](https://www.google.com/maps/d/u/1/edit?mid=1OScN37smu3dWN9w1_W2gHDDP3HwNySP4&usp=sharing)  
 251 *map 2: <https://www.google.com/maps/d/u/1/edit?mid=11HBRW5Ogpm3RPbJ4L-0O25KS0OyIbru2&usp=sharing> color code:*  
 252 *grey refers to urban pilot sites, blue to freshwater/watersheds and green for natural areas. A detailed representation of each*  
 253 *projects NBS-NBaS can be found on <https://cloud.enpc.fr/s/damrKF3zZzpCKiT>*

254 As can be seen from Figure 2, many sites are scattered across the European continent. Accordingly, the  
 255 most targeted climatic regions are the temperate continental climate, the oceanic and northern temperate  
 256 regimes and the Mediterranean climate (Nikolaïdis et al., 2019). The interest in the latter is particularly  
 257 translated by the dense concentration of pilot areas in Southern Europe. This can be attributed to the  
 258 following reasons: 1) The Mediterranean climate is expected to be the most impacted by climate change  
 259 and its manifestations (Finér et al., 2019; Grace et al., 2021); and 2) The need for more evidence on the  
 260 efficiency and co-benefits of NBS-NBaS as well as on the ecological responses of Mediterranean  
 261 ecosystems under changing environmental conditions (Balzan et al., 2020 and IUCN 2019 in Grace et al.  
 262 2021). Northern and Eastern Europe display scattered concentrations with much less sites in the Eastern  
 263 part. This may be due to: 1) the limited number of scientific publications on NBS in Eastern Europe since  
 264 2005 (Cooper et al., 2018), 2) the lesser number of scientific publications on NBS-NBaS in Eastern Europe  
 265 with respect to the Western counterpart (Hanson et al., 2017) and 3) less projects are based in this region.  
 266 At a finer scale, Figure 3 shows that most pilot sites are concentrated in Italy, Spain, Germany and France.

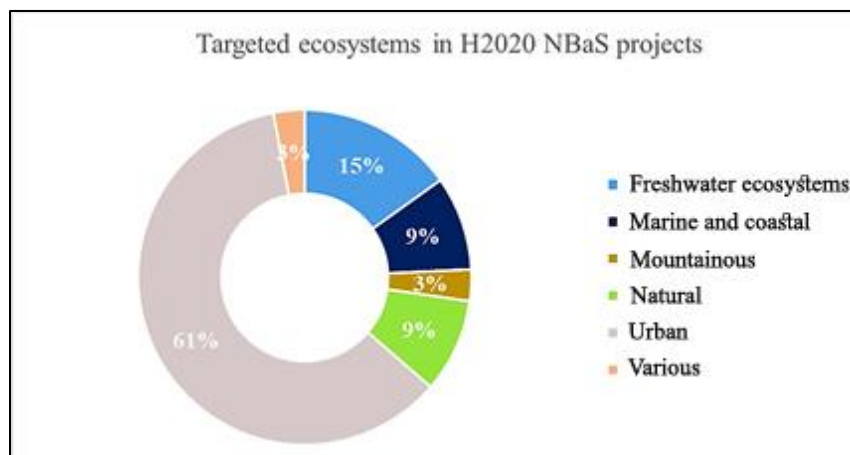
267  
 268  
 269  
 270  
 271



272  
273 *Figure 3: Location of the pilot sites of European countries in H2020 projects*

274 **3.4. Target ecosystems, challenges and NBaS**

275 The targeted ecosystems in each project are presented in Figure 4 (from each project’s pilot sites). As can  
 276 be seen, the urban environment predominates the H2020 NBaS projects landscape (61%). This distribution  
 277 reflects the current European strategies that are mostly focused on cities and urban contexts under climate  
 278 change and demographic development. However, this interest comes at the expense of other media that are  
 279 significantly underrepresented and understudied. Accordingly, the coastal (9%) and mountainous  
 280 environment (3%) are remarkably overlooked with coastal resilience and marine protection being one of  
 281 the least targeted goals (Hanson et al., 2017; Nikolaidis et al., 2019; Ruangpan et al., 2020; Veerkamp et  
 282 al., 2018), while mountainous environment is only targeted by a single project (PHUSICOS). Strikingly,  
 283 the agricultural medium is absent as a distinct ecosystem, despite its marginal occurrence as pilot  
 284 intervention site in some projects.



285  
286 *Figure 4: Target ecosystems of H2020 NBaS projects*

287 In terms of climatic challenges, urban heat islands, coastal hazards (mostly in relation to urban coastal  
 288 settings), floods, sea level rise, heavy rainfall, temperature rises, heat stress, erosion, landslides, and storm  
 289 surges are the most addressed. From these challenges, flooding occupies the top position and is almost  
 290 present in all intervention sites (Debele et al., 2019). Urban Heat Islands (UHI) are the second topmost

291 addressed challenge. While UHI mostly concern the urban environment, other challenges are cross-  
292 sectorial. However, the focus on urban ecosystems, as a result of the increasing number of urban  
293 populations, reduces the efforts needed to address the above-mentioned challenges in other media. Another  
294 tier of challenges throughout the projects focus on socioeconomic disadvantages, social inequities,  
295 vulnerable populations' status, human health, environmental and resource degradation, overpopulation, air  
296 quality, reduction of green cover, agricultural decline, etc. However, these are beyond the scope of this  
297 study as the latter focuses more on the biophysical angles of NBS-NBaS.

298 The dominant focus on urban ecosystems makes urban green solutions (green parks, urban forests,  
299 ecological corridors, etc.) and blue-green infrastructure (green roofs, urban wetlands, ponds, grass  
300 waterways, etc.) the most studied type of NBaS, thus missing out on a variety of other non-urban solutions.  
301 Moreover, targeting the urban realm which ranges from the building to the city level at best, relatively  
302 covers small scale interventions. This "narrow scale" approach leads to missing out on macroscale  
303 interventions and subsequent large scale NBS-NBaS. Given the large focus on urban systems, most  
304 presented solutions correspond to Type 3 (i.e. NBS that target the management or creation of new  
305 ecosystems, e.g. urban parks, green roofs, etc.), and to a lesser extent to Type 2 NBS (i.e. interventions in  
306 managed ecosystems and landscapes, e.g. agrobiodiversity, agroecology, etc.). Type 1 (i.e. minimal  
307 interventions – protected ecosystems, e.g. protected areas) are relatively rarely to never targeted. This  
308 distribution signifies that most efforts are concentrated on a particular type of NBS-NBaS, leaving behind  
309 and potentially missing out on the potential of others. These observations converge with those of Wendling  
310 et al. (2019) who reported that most European NBS are of type 3 nature.

### 311 **3.5. Current knowledge and limitations per ecosystem**

312 In this section, a state-of-the-art from H2020 literature on current knowledge and identified limits is  
313 presented. Outcomes of this section were the basis for formulating the research perspectives and lines of  
314 work proposed in the conclusion section.

#### 315 ***3.5.1. The urban ecosystem***

316 The European Commission focuses mostly on the urban medium due to two main reasons: i) the increasing  
317 number of European populations living in cities, and ii) the urge to address numerous challenges, namely  
318 climate change, impacts on human health, and the degradation of natural capital (Cohen-Shacham et al.,  
319 2019). Despite being major contributors to climate change, and one of the most affected contexts, cities can  
320 also be part of the solution (Arlati et al., 2021; Gerstetter et al., 2020; Knoblauch et al., 2019; Tozer and  
321 Xie, 2020). This is mainly due to the long term accumulation of emitted carbon dioxide in urban vegetation  
322 and underlying soils as underlined by Richter et al. (2020) for the CLEARING HOUSE and Connecting  
323 Nature projects.

324 The concept of NBS is the most recent entry in the debate on nature's role for increasing the climatic  
325 resilience of urban settings (Bailly et al., 2019b; O'Sullivan et al., 2020). In urban settings, NBS are being  
326 developed as part of urban climate infrastructure strategies for which cities use resilience principles as a  
327 guiding framework (Oke et al., 2021). According to the CLEVER Cities framework, the logic behind this  
328 approach is that NBS allow progress towards flexible and equitable urban resilience while promoting CCA  
329 (Mahmoud and Morello, 2018). According to the euPOLIS project, NBS are also considered as key factors  
330 for retrofitting and rehabilitating existing urban areas (Maksimovic et al., 2021) and also contribute to urban  
331 biodiversity (Xie and Bulkeley, 2020). For the REGREEN project, at this level the role of biodiversity is  
332 multi-leveled: a) it can be part of the NBS-NBaS, b) it can serve as an important attribute to help the sought  
333 solutions withstand pressures such as climate change, or c) it can be obtained as an end product from the  
334 implemented solution (Fletcher et al., 2020). Nonetheless, as highlighted by the NATURVATION project,  
335 the approach to urban NBS-NBaS biodiversity is not very centric, but rather focuses on ecosystem-based  
336 approaches for protecting and restoring functionalities, or ensuring the connectivity of habitats (Xie and  
337 Bulkeley, 2020).

338 Most research on NBS in the urban environment is biased towards disciplinary perspectives (Haase et al.,  
339 2014 *in* Veerkamp et al. 2018). In this regard, according to the Connecting Nature project, there is a new  
340 role of science with cities instead of science for cities (Holscher et al., 2019). Science for cities represents  
341 a somehow rigid approach where generated knowledge is often trapped in disciplinary silos. On the other  
342 hand, science for with cities is perhaps a more flexible concept as it includes the active participation of the  
343 city's inhabitants and other urban stakeholders. Accordingly, the shift from "science for" to "science with",  
344 ensures the democratization of knowledge on cities (Carton and Ache, 2017 *in* Holscher et al. 2019).  
345 However, as most city science is generated by consultants, scientific researchers are needed to generate  
346 new knowledge in addition to synthesizing already existing information (Holscher et al., 2019). To this end,  
347 a scientist's critical logic can be beneficial for providing perspectives and recommendations that take into  
348 consideration the complexity of cities and the urban climate (Steiner, 2014 *in* Holscher et al. 2019).  
349 However, many elements related to the urban realm still pose significant challenges for this task, these can  
350 be considered as current knowledge limits that should evolve into research lines of work:

351 First, the relationship between nature and cities is inversely proportional for its most part (Bailly et al.,  
352 2019a). In this regard, there is a need to clearly define all aspects of the city-nature relationship and  
353 determine how the trade-offs between these two different ecosystems (urban-nature) can be balanced in  
354 terms of service provision and delivery, as well as to understand the negative feedback loops and counteract  
355 them. Second, the urban context is highly non-uniform as it is formed from a mosaic of different systems,  
356 landscapes and media (Bulkeley and Raven, 2018). Similarly, urban nature extends beyond the  
357 misconception of scarce vegetation and artificial nature, and englobes water, lands, soils, air, and energy  
358 (Bailly et al., 2019b). The often oversimplified representation of the urban realm undermines the  
359 contribution of different land cover elements to the modification or creation of services or processes (Babi  
360 Almenar et al., 2018). Therefore, according to Nature4Cities, any approach should consider this  
361 heterogeneity to adequately define the challenge in hand and the subsequent solutions. Nonetheless,  
362 complex approaches to mosaics of ecosystems are still rare. This is due to the fact that ecosystems, much  
363 like their services, are not bound by geographical boundaries, which means that these engage in loops that  
364 aren't still well understood. To this end, a mosaic of ecosystems means different tipping points, different  
365 ecological thresholds and different responses. Therefore, no solution can be accurately designed without a  
366 sufficient understanding of the stated elements. While this aspect is certainly difficult and bound by many  
367 challenges, it remains a necessary line of work to develop.

368 Third, ongoing urbanization constrains planners and scientists to design solutions in continuously limited  
369 spaces (Knaus and Haase, 2020). This is also compounded by the fact that turning impervious areas to green  
370 or blue spaces often conflicts with the need of building more housing structures. Therefore, space-sensitive  
371 solutions are needed (Knaus and Haase, 2020). Nonetheless, space-sensitive solutions often imply small-  
372 scale interventions. The efficiency of small-scale interventions, particularly for large scale challenges such  
373 as climate change is yet to be decisive. To this end, NBaS for microclimate adaptation (i.e. a proportional  
374 scale to the proposed solutions) might be a more logical approach to develop. Fourth, the urban setting is a  
375 multi-scalar context, it encompasses different scales from the building, to the urban zone and ultimately the  
376 cityscape level (Somarakis et al., 2019). The multiplicity of scales complicates the choice of a scale-efficient  
377 solution. For instance, a green roof at the building scale will have a negligible effect at the cityscape level  
378 in terms of cooling. Likewise, an urban park at street level while have negligible effects at the building  
379 scale.

380 Lastly, isolated NBS-NBaS (small interventions) can collapse under the "harshness" of the urban realm  
381 where entwined pressures may significantly surpass the solutions' capacity and cause an inflexion of their  
382 functions (Bailly et al. 2019a). In this vein, understanding the interactions between the solution and the  
383 medium it has been introduced in is an important platform to consider. Often, NBaS are wrongfully  
384 introduced as immune systems without considering how the components of the ecosystems they were  
385 introduced into influence their survival/efficiency. The most studied solutions are urban parks and forests,  
386 followed by urban green spaces, blue areas, and community gardens (Cooper et al., 2018). Accordingly,

387 there is a need for mapping and deriving more evidence from a wide range of NBS other than Blue Green  
388 Infrastructure (BGI) (Hanson et al., 2017).

389 *The urban climate, water management and related solutions*

390 What differentiates the urban medium from others is its particular climatic behavior. This is mainly due to  
391 the multitude of land covers that form the urban settings and the morphology of cities (degree of  
392 compaction, building heights, extension and sprawling). UHIs are the most studied and documented urban  
393 climate phenomena (Bailly et al., 2019a). According to the GrowGreen project, they have become central  
394 elements of planning particularly under an ever changing climate (Gutierrez et al., 2020). Water  
395 management comes second after UHI and is particularly addressed for stormwater management and urban  
396 flooding reduction. In response to both challenges, green cover expansion and green roof installation are  
397 the most frequent solutions throughout the retained projects. In what follows, an explanation of each one's  
398 effects along with knowledge needs are presented

399 *Trees*

400 Street trees, along with other types of plantation, are considered as some of the most used solutions for  
401 attending to UHIs. Through evaporative cooling they tend to reduce local temperatures while enhancing air  
402 quality through photosynthesis. Nonetheless, there have been reports on disruption of air flows and creation  
403 of localized heat pockets as a result of tree configurations. In addition, negative effects on air quality have  
404 been reported due to blocking of ventilation within street canyons as a result of specific configurations of  
405 connected trees.

406 Trees are also considered as key elements for stormwater management in urban settings through  
407 precipitation interception, runoff reduction, increased evapotranspiration and infiltration (Baker et al.,  
408 2021). However, as highlighted by Baker et al. (2021) in the REGREEN project, the extent of their  
409 efficiency has yet to be defined, and related literature hasn't been objectively reviewed. They are also  
410 efficient measures for reducing temperatures through evaporative fluxes and shading. According to the  
411 Connecting Nature projects, if tree-based solutions are imperfectly designed, they can disrupt air flow,  
412 hence causing localized increases in air temperatures (Connop et al., 2020). While the general consensus is  
413 that temperature increases in urban environments will only worsen UHIs, these may also induce longer  
414 vegetation growing season, increased photosynthesis rates, and hence more carbon storage (Vasenev and  
415 Kuzyakov, 2018 in Richter et al., 2020). This could also possibly mean promoted cooling as a result of  
416 biomass growth or development. Nonetheless, these feedbacks should be better understood when an NBS-  
417 NBaS is designed. At this level, according to proGReg, the definition of buffer zones for the analysis of  
418 NBS-NBaS impacts could be helpful as their effect may not extend beyond a certain zone (Leopa and Elisei,  
419 2020) particularly for cooling. The arrangement of trees in cities dictates the nature of the solution, however  
420 evidence on the effect of tree arrangement for maximizing performances and benefits is inconclusive (Baker  
421 et al., 2021). Considering this aspect is important as tree arrangement is often dictated by space availability  
422 in cities. Regardless of their sizes and arrangements, trees and green covers address CCA and Climate  
423 Change Mitigation (CCM) simultaneously as they can sequester carbon while reducing temperatures (Tozer  
424 and Xie 2020). However, prior to the design and implementation of any green solution, several factors  
425 should be accounted for. For instance, some green solutions are irrigation dependent. This raises concerns  
426 in terms of resource efficiency, particularly in the context of climate change where water scarcity is  
427 expected to increase and droughts to extend further. In this context, the resource efficiency (consumption  
428 versus generation/conservation potential) of any planned solution should be better investigated as  
429 throughout their existence NBaS consume natural capital in their own rights. Understanding how NBS-  
430 NBaS utilize natural resource and nature is relatively an unexplored line of work.

431 Even if green spaces are perceived as performant NBS-NBaS, heatwaves and extended drought periods  
432 can severely degrade them (Morakinyo et al., 2017). Additionally, tree (particularly juvenile ones) survival  
433 rate is very low during the first year as these are prone to be affected by climate change and particularly

434 heat stress (Richter et al., 2020). Accordingly, what seems to be a solution to an intended problem can also  
435 be susceptible to the challenge it was intended to address.

436 *Green roofs: A solution for limited spaces*

437 Green roofs are very widely targeted under various H2020 urban projects. As reported by Urban GreenUP,  
438 in cities infrastructural and space availability challenges can limit the expansion of NBS-NBaS (Kuban et  
439 al., 2019). That is why cities often cannot support large NBS projects (Bailly et al., 2019b). For this purpose,  
440 green roofs are considered as some of the most effective multi-purpose “ground-free” solutions that are  
441 ideal for cities and their continuous densification (Knaus and Haase, 2020). According to Zölch et al. (2017)  
442 in Baker et al. (2021), green roofs even outperform trees in terms of runoff reduction due to their larger  
443 permeable surfaces when aggregated, as opposed to the limited surface of trees planted in urban settings.  
444 The most decisive factor for a green roof is its substrate as it also defines its type, i.e. extensive or intensive  
445 (Knaus and Haase, 2020). Most green roof studies focus on extensive roofs rather than intensive ones  
446 (Knaus and Haase, 2020), despite the fact that the latter outperform the former on an environmental scale  
447 (Morakinyo et al., 2017 in Knaus and Haase, 2020). In this vein, intensive green roofs are more efficient in  
448 terms of stormwater management, control of dissolved pollutants, evaporative cooling as a result of higher  
449 biomass indices, and biodiversity support (Cascone, 2019).

450 Regardless of their types, these roofs are mainly used for climate resilience and long-term urban water  
451 management (Snep et al., 2020). They are important surfaces for ecological compensation in cities, and  
452 have a large potential for renaturing urban contexts (Santos et al., 2016). They effectively retain incoming  
453 water, help in CCA/CCM, modify surface energy balances, reduce runoff/peak flows, and promote urban  
454 biodiversity (Pardela et al., 2020). Whether intensive or extensive, the performance of green roofs for  
455 stormwater management is highly related to rainfall events and the initial saturation of their substrate.

456 Many studies report several insights on the behavior of green roofs on peak reduction and water retention  
457 However, lesser studies focus on assessing their impact on temperature reduction (Jamei et al., 2021). In a  
458 study on the effect of green roofs’ in a neighborhood located in central Berlin Germany, Knaus and Haase  
459 (2020), found the following:

460 i) In relation to the CLEARING HOUSE and CONNECTING Nature projects, at a street level, the cooling  
461 effect of green roofs is very minor with values as low as 0.04°C (mean temperature reduction). On a  
462 pedestrian level, the maximal reduction effect is of 0.3 °C (with a mean of 0.1 °C), also negligible. ii) The  
463 most pronounced effects on temperature are observed at the roof’s level with a decrease of surface  
464 temperature by as much as 26 °C, Physiological Equivalent Temperature (PET) by 4 °C compared to street-  
465 level, and by 9 °C when compared with a non-green roof, and iii) in areas of mid to high buildings, the  
466 down spill of cool air generated by green roofs hardly reaches the street. According to Müller et al., (2014)  
467 in Knaus and Haase (2020), the downward effect of green roofs is negligible for buildings higher than 10  
468 meters.

469 However, these findings are case-specific and are applicable to the specific conditions they were found in  
470 (Davis et al., 2018). In a different climatic setting, different behavior could be expected. Regardless of their  
471 exact number, in general terms the above-mentioned findings indicate that the effect of green roofs is only  
472 pronounced at the level of the building they are located on, and hence do not replace ground greening (in  
473 terms of cooling), but can be only considered as a complementary effort (Knaus and Haase 2020). However,  
474 when considering the surface of green roofs when spread over the city, a considerable increase of green  
475 cover can be noted (Knaus and Haase 2020). Another advantage of green roofs is that these can be coupled  
476 to other solutions. For instance, urban farming on a green roof (Somarakis et al., 2019), or a constructed  
477 wet roof that combines an extensive green roof and a constructed wetland for water treatment (UNaLab,  
478 2019). However, further investigations on the combined effects of ground and roof solutions are still a line  
479 of work to develop.

480 **3.5.2. Freshwater ecosystems**

481 The freshwater medium is the second most targeted ecosystem under the H2020 projects. In each project,  
482 different freshwater realms of various scales are present. These range from lakes, to rivers, to river networks  
483 and watersheds. Most of the prevalent measures are of structural or functional measures. Examples are river  
484 restoration, floodplain enlarging, river meandering, daylighting, installation of levees, wetland restoration,  
485 modification of the hydrologic network (connection/disconnection), retention basins and others. At this  
486 level, nature contributes to CCA through flood management and the provision of better water quality (Bailly  
487 et al., 2019b). Water quality is mainly addressed through phytoremediation, the use of wetlands or other  
488 small water retention features for sediment or soil bound pollutant retention. Another measure is the  
489 installation of grass or vegetation belts and canals around waterbodies to protect the latter from pollutant  
490 bound runoff from neighboring systems (urban or agricultural). In river management and flooding, several  
491 projects highlighted many factors that are responsible for the complexity and difficulty of NBS-NBaS.  
492 According to the ThinkNature project, the multitude of factors that interfere [i.e. socioeconomic, climatic,  
493 geological, and geomorphological, etc] (Banwart et al., 2018) make the design and conceptualization of  
494 these solutions complicated. Moreover, the challenges involved call for different scales, and that itself is a  
495 considerable barrier; for instance, pluvial flooding requires an urban zone scale, while river flooding  
496 requires a whole watershed scale approach (Somarakis et al., 2019). For NAIAD, the role of ecosystems  
497 (underlying basis of NBS and NBaS) on water supplies is still an open empirical research topic (Hérivaux  
498 et al., 2019). Also, the size and location of NBS-NBaS is also an important factor to consider. According  
499 to Burke et al. (2018) as part of the NAIAD project, small (many) interventions should be concentrated in  
500 upper watershed sections where flows are less than the downstream parts where large interventions should  
501 take place.

502 For OPERANDUM, the same hazard, e.g. flooding, can be initiated by different triggering factors. For  
503 instance, river floods can be initiated by precipitation in a particular context (e.g. Western Europe), while  
504 in other regions (e.g. Northern Europe), snow melt can be the main reason (Aguzzi et al., 2019). An example  
505 would be the case of Finland (Finér et al., 2019), where significant efforts are needed to take into  
506 consideration the effect of melting, its timing (changes) and the effects on the sought solutions.  
507 Accordingly, sought solutions in these contexts should take account for these manifestations along with  
508 other ones. Therefore the same NBS-NBaS for the same freshwater hazard cannot be applicable in different  
509 locations.

510 In terms of flooding, NBS-NBaS are designed to increase floodwater storage capacities upstream of the  
511 studied contexts (Muligan et al., 2017). Storage capacities usually concern four compartments: water  
512 bodies, canopy, floodplains and soil (Muligan et al., 2017). Increasing the storage capacity of any  
513 compartment impacts flood hydrographs by reducing the velocity of floodwaters, influencing peak flows  
514 and buffering risks in both the river and downstream sections (Muligan et al., 2017). Van Soesbergen and  
515 Mulligan (2018) found through storage capacity analyses that targeting soil and canopy storages was needed  
516 to reduce flood risk. While several NBS-NBaS target the floodplain (e.g. floodplain enlarging), water body  
517 (e.g. river restoration and daylighting) and canopy compartments (e.g. increase of green cover), rare are  
518 those who target soils despite the fact that increased soil infiltration can significantly reduce flood risks  
519 (Muligan et al., 2017). Infiltration solutions are also potent drought NBS-NBaS as these can increase  
520 groundwater storage (Muligan et al., 2017). However, groundwater systems are not routinely monitored  
521 (Douglas et al., 2019). Moreover, increased infiltration is not always an advantage as in contexts where  
522 groundwater supply is high increasing infiltration will only compound groundwater flooding risks due to  
523 water table rise (Hérivaux et al., 2019). A relevant example is karst saturation as the latter can lead to  
524 amplified risks particularly when soil saturation is also high (Graveline et al., 2018). It is also important to  
525 understand how NBS-NBaS can influence groundwater levels after extreme events (Pérez-Lapena et al.,  
526 2018). In this vein, the groundwater-aquifer-NBS nexus has been highlighted in several sources (such as  
527 the OPERANDUM project) as a significant gap to address particularly given their importance for attending  
528 to droughts and floods simultaneously (Tuomenvirta et al., 2019).



529 Currently, flooding is mainly addressed using hybrid solutions (Debele et al., 2019). According to CLEVER  
530 Cities, in the green versus grey debate, NBS-NBaS often lose the argument of collected experience and  
531 evidence compared to grey infrastructures (Knoblauch et al., 2019). Therefore, the ThinkNature project  
532 underlines the need to develop tools and indicators for assessing mixed solutions (Nikolaidis et al., 2019).  
533 According to NATURVATION, the environmental impact of hybrid solutions also requires further  
534 investigations (Kiss et al., 2019). It is therefore logical to question if NBS-NBaS are fully capable of  
535 masking the disruptive effect of their grey counterparts. For RECONNECT, the latter's performance under  
536 an uncertain evolution of climate is also still relatively unknown, and can be considered as an important  
537 line of work to explore (Watkin et al., 2019). Under this context, significant efforts are needed for the  
538 assessment of large scale NBS-NBaS, watershed scale NBS-NBaS and hybrid structures that contain both  
539 small and large NBS (Watkin et al., 2019).

540 It is worthwhile mentioning that an important aspect of freshwater systems is targeted through the DRYvER  
541 project. The latter is the only H2020 project that considers intermittency of water bodies. Although the  
542 project is still undergoing, the work done by Messenger et al. (2021) provides solid arguments on the gaps  
543 this project is filling. According to the same Authors, unlike rivers and permanent streams, the value and  
544 future of intermittent water bodies are often undermined, understudied and overlooked (Messenger et al.,  
545 2021). Until recently, freshwater sciences were particularly concentrated on perennial water bodies, and it  
546 isn't until lately that scientists acknowledged the seriousness of intermittent water bodies' degradation  
547 (Messenger et al., 2021). As a result, the related scientific methods and management tools are either limited  
548 or absent (Messenger et al., 2021). In a map presented by the same Authors, stream intermittency was shown  
549 to be particularly pronounced in Southern Europe (i.e. the region under Mediterranean climate) where  
550 droughts are causing significant stress on water resources. However, as mentioned-above, this discipline is  
551 still nascent and more significant efforts are needed.

### 552 *3.5.3. Marine and coastal ecosystems*

553 The EC's seven NBS actions for R&I are according to Morello et al. (2018): Urban regeneration through  
554 NBS, NBS for well-being in urban areas, NBS for coastal resilience, multi-functional nature-based  
555 watershed management and ecosystem restoration, NBS for sustainability of the use of matter and energy,  
556 NBS for enhancing the insurance value of ecosystems, and NBS for carbon sequestration. Despite the high  
557 rank of coastal resilience on this list, coastal areas are very rarely addressed within the NBS-NBaS  
558 framework (Ruangpan et al., 2020) and through the H2020 NBaS projects. In a review performed by  
559 Hanson et al. (2017), climate action for adaptation, resilience and mitigation were found to be NBS priority  
560 number one, while coastal resilience was quasi-absent. Another review by Nikolaidis et al. (2019) for case  
561 studies in the ThinkNature database revealed that coastal resilience is also one of the least targeted goals.  
562 The same was also found in a review conducted by Veerkamp et al. (2018), where climate adaptation,  
563 resilience and mitigation were found to be the most targeted aspects within ecosystem service assessment,  
564 in contrast to coastal resilience and marine protection. Several of the retained projects target coastal areas  
565 as part of their pilot zones. However, only two H2020 NBaS project are dedicated for coastal and marine  
566 areas (FutureMARES and MaCoBioS). Both are still undergoing (2020-2024) and consequently not many  
567 related references have been produced during the time of this study. Therefore, not much research gaps  
568 were extracted from these projects.

569 However, a general picture of current knowledge shows that the underrepresentation of marine and coastal  
570 ecosystems is surprising, since these are some of the most influenced contexts by hydrometeorological  
571 hazards and climate change (Debele et al., 2019). The complexity of these settings might be a reason  
572 (Dudley et al., 2010), as challenges in these systems may be closely overlapping [e.g. coastal resilience and  
573 climate change] (Bulkeley and Raven, 2018). Some hazards may be also interlinked, for instance storm  
574 surges and coastal erosion have a cause-consequence relationship (Debele et al., 2019). Under the current  
575 reviewed offer (excluding FutureMARES and MaCoBioS), coastal erosion is an addressed hazard in coastal  
576 urban contexts (coastal cities). The main objective behind this approach is to protect or adapt the concerned

577 cities to coastal hazards. As such, coastal resilience and the coastal ecosystem are not targeted for land loss,  
578 sediment balance, foreshore stability or seafloor configuration (i.e. the ecosystem's intrinsic value), but for  
579 the sake of the urban system. This indicates that the importance of an ecosystem increases only when an  
580 urban context is in vicinity. Subsequently, the proposed NBS-NBaS will be indirectly implemented as  
581 utilitarian anthropocentric interventions. Moreover, the solutions offered by marine and coastal ecosystems  
582 are also somewhat underutilized despite their potential. For instance, marine habitats such as seagrass, salt  
583 marshes, mangroves, coastal wetlands and kelp forests, coral and shellfish reefs are efficient coastal  
584 protection elements that help adapt to increased storms, sea level rise and climate change induced floods  
585 (FutureMARES, 2021). For example, salt marshes and coral reefs are capable of decreasing flood waves  
586 by 70% and 72% on average (Debele et al., 2019). However, these are still underused and are not studied  
587 as much as green or blue-green solutions. Much of these solutions are expected to be implemented and  
588 studied in the FutureMARES and MaCoBioS project, and hence considerable knowledge is expected to be  
589 generated. However, during the time of this study, no data was yet available.

#### 590 **3.5.4. Mountainous ecosystems**

591 The mountainous medium is the least targeted ecosystem in H2020 projects. The only dedicated project is  
592 PHUSICOS that aims to demonstrate how NBS can reduce risks in mountainous landscapes. Currently,  
593 none of the present platforms on NBS are specifically focused on natural risks in hilly and mountainous  
594 regions (Baills et al., 2021), nor on climate change adaptation. Despite the role of mountains in amplifying  
595 hydrometeorological risks, particularly under a changing climate, not much attention is given to these  
596 environments especially in European Disaster Risk Reduction (DRR) plans (Autuori et al., 2019).  
597 Accordingly, very little research on NBS for DRR in mountainous environments has been conducted so far  
598 (Accastello et al., 2019 in Martin et al., 2019). In the very few studies, most address floods while fewer  
599 target landslide and rockfall hazards (Baills et al., 2021). To this end, success stories of NBS-NBaS for  
600 landslide and flood mitigation in rural and mountainous areas are still meagre (Solheim et al., 2021). When  
601 considered, most solutions consist of forests (afforestation/reforestation) for stabilizing slopes, reducing  
602 rockfall, landslides and avalanches as well as for buffering flood risks.

#### 603 **3.5.5. Forest and natural (protected areas) ecosystems**

604 Within most of the retained projects, forests are some of the most common solutions (e.g. Clearing House,  
605 OPERANDUM, euPOLIS, RECONNECT and UNaLab, etc.), but are rarely addressed as target ecosystems.  
606 The range of environmental challenges that forests are used as solutions to is wide, and spans across climate  
607 change adaptation/mitigation, disaster risk reduction, biodiversity support, climatic regulation, stormwater  
608 management, air regulation, erosion counteraction, water quality support, floodplain restoration, and others.  
609 Seemingly, trees and forests are “the” solution for almost all environmental challenges in different  
610 ecosystems. Under the retained projects, most of their use was concentrated in the urban ecosystem. Within  
611 the latter, urban forests are designed/implemented for various objectives. For instance, in the URBiNAT  
612 project, urban forests in Brussels (Belgium) are proposed as solutions for urban heat island and flood  
613 mitigation. Under Nature4Cities, urban forests are used among other solutions for rehabilitating the  
614 waterfront of the Tisza River in the Szeged Municipality of Hungary. In the same project, urban forests are  
615 used in Alcalà de Henares (Spain) for heat comfort, as part of edible solutions and for renaturalisation. For  
616 the Clearing House project, urban forests are used in Barcelona (Spain) for river catchment restoration and  
617 for the delivery of green infrastructure strategies. In Brussels (Belgium), urban forests are used for  
618 enhancing urban-rural territorial linkage, while in Gelsenkirchen (Germany), they are used as means for  
619 restoring former mining sites, urban and sociocultural regeneration. In Kraków (Poland), urban forests are  
620 used for air quality improvement, while in Leipzig-Halle (Germany) they are used for river catchment  
621 restoration, increasing the attractiveness of the site and for nature connectivity.

622 In other than urban systems (namely the mountainous environment and watersheds), forests were mostly  
623 used for risk reduction (landslide and flood risk reduction, respectively).

624 In their own right, protected areas are relatively untapped despite their spread across the European continent  
625 (Natura 2000, regional parks, and others). This is a major research gap to address, as the potential of these  
626 solutions is relatively underutilized in NBaS projects. This could be due to the fact that the urban medium  
627 is the most favored ecosystem, and that protected areas do not correspond much to urban priorities.  
628 However, when implemented at the outskirts of cities or urban contexts, protected areas can increase the  
629 connectivity between urban, peri-urban and rural contexts, thus promoting the resilience of urban  
630 ecosystems (Naumann and Davis, 2020). Moreover, the use of protected areas as means to protect other  
631 NBaS is not very developed. While some projects propose the use of buffer strips to protect downstream  
632 waterbodies from agricultural runoff, none make use of protected areas for the same purpose (protection of  
633 other NBaS). This could be an interesting line of work to develop for maximizing the use of protected areas  
634 as part of NBaS or for their protection. In terms of marine protected areas, the narrow focus on marine  
635 environments can also be a reason for the relative absence of protected areas. On these bases, significant  
636 efforts are needed to leverage the use of protected areas (both terrestrial and aquatic) as NBS-NBaS, and to  
637 define relevant knowledge and research needs. The latter might be addressed throughout the EU's far-  
638 reaching 2030 biodiversity strategy that will transform at least 30 percent of Europe's lands and seas into  
639 effectively managed protected areas (GEF, 2020).

### 640 **3.5.6. Agricultural medium**

641 The agricultural medium as an ecosystem of interest is absent. Many projects target agriculture in some  
642 related pilot sites, however not as a primary focus. The absence of the agricultural sector as a biome of  
643 interest is a significant element to consider given the importance of the latter for food security and the  
644 sustainability of humans and ecosystems. While edible solutions have been proposed as part of urban  
645 agriculture in the EdiCitNet project, very few other solutions are proposed. The reduced interest in the  
646 agricultural sector causes a subsequent underrepresentation of agricultural NBS-NBaS, and hence  
647 underlines a major gap to address.

## 648 **3.6. Current knowledge and limitations per main research topic**

### 649 **3.6.1. Climate change and adaptation**

650 A wide range of discussion on the underlying concepts and bases of climate change is available throughout  
651 the different references. The current red line threshold is the 2 °C increase, beyond which climate change  
652 is assumed to become dangerous and its effects on ecosystems irreversible (Garcia Blanco et al., 2021).  
653 Therefore, adaptation to climate change stands first among the priority areas mentioned in international,  
654 European, national, local and regional policies reviewed by Knoblauch et al. (2019). Mitigation of climate  
655 change is also of equal importance, in an effort to keep warming beyond the 2 °C limit. All projects agree  
656 with Grow Green's insight that in the face of a changing climate, adaptive policymaking is needed to  
657 account for uncertainties, while a certain degree of flexibility is inevitable to avoid robust decision making  
658 (Zorita et al., 2021). The importance of research at this level lies not only in the generation of a successful  
659 solution, but also in refining interventions once implemented (Naylor et al. 2012 in Kiss et al. 2019). A  
660 general agreement on the importance of environmental risk evaluation for ensuring the success of NBaS  
661 and NBS for CCM (Garcia Blanco et al., 2021) is also common between the projects. Most projects  
662 approach CCA from the IPCC's (2014) perspective, where risk is expressed as a function of hazard,  
663 exposure and vulnerability. To this end, an analysis of all three risk components is often seen throughout  
664 the projects. Accordingly, this can be considered as a lever to overcome the classical confusion between  
665 risk and hazard in climate-related risk assessments (Kumar et al., 2019). Nonetheless, several challenges  
666 are apparent due to the difficulty of calculating/quantifying the occurrence probabilities for climatic hazards  
667 (Kumar et al., 2019), and the short-term variability of exposures and vulnerabilities due to intra annual  
668 variations (Fletcher et al., 2020).

669 In the case of NBS (including NBaS), mitigation and adaptation are closely entwined as any adaptation  
670 activity will promote mitigation potential and subsequently promote climate resilience (GMV et al., 2019).

671 To this end, both NBaS and NBS for CCM commonly aim to enhance ecosystemic resilience and stabilize  
672 ecoservices (Morello et al., 2018). For NBaS specifically, the aim is 1) to preserve the services needed by  
673 humans to make the impacts of climate change less adverse (Bailly et al., 2019b); and 2) to decrease the  
674 impact of the expected climatic effects (Morello et al., 2018). However, it is possible for a NBaS to target  
675 CCM (Morello et al., 2018), hence the advantage of these solutions. For example, a green park established  
676 from reducing the Urban Heat Island (UHI) effect [CCA] can simultaneously store carbon in its above and  
677 below ground components [CCM]. Another strong point of NBaS is that they cover the cross-cutting  
678 elements of climate action, i.e. environmental, social, cultural, and economic factors (Tozer and Xie, 2020)  
679 through the provision of multi-benefits. Xie and Bulkeley (2020) reported that NBaS and NBS for CCM  
680 were found to operate on five levels: 1) flood prevention and regulation, 2) UHI mitigation, 3) carbon  
681 sequestration-reduction of emissions, 4) microclimate enhancement and 5) drought and desertification  
682 prevention or reduction. From the levels mentioned, one can notice that some elements are related to climate  
683 change impacts mitigation rather than CCM itself. In the same vein, levels 1 and 5 are closer to adaptation.  
684 This intersection between CCA and CCM underlines the mutually beneficial nature of NBS-NBaS, hence  
685 their importance for action on climate.

686 In the case of NBaS, current research efforts are mostly focused on green infrastructures, ecological  
687 connective functions and ecoservices provision for climate change resilience (Collier, 2021). However, a  
688 significant knowledge gap for assessing the impact of NBaS across a range of climate resilience challenges,  
689 and through different geographic levels exists (Somarakis et al., 2019). Another gap concerning the  
690 assessment of their long-term effectiveness under climate change scenarios is also prevalent (Bowyer et al.,  
691 2020; Gómez Martín et al., 2021). This last point should be particularly focused on as it can help understand  
692 the conditions these solutions will face and will have to perform under (Bowyer et al., 2020).

693 From the five levels listed by Xie and Bulkeley (2020), flood (Debele et al., 2019) and drought-related  
694 NBS-NBaS still require significant efforts (Xie and Bulkeley, 2020). In the case of droughts, research needs  
695 are more pronounced as studies on NBS-NBaS for slow onset events and their post-occurrence effects are  
696 still limited (Tuomenvirta et al., 2019). Within some of the pilot sites that include droughts, the latter are  
697 mainly addressed as a lack of precipitation (e.g. Mayor et al., 2018). This may be due to their confusion  
698 with water scarcity which is also often wrongly used as a synonym (GMV et al., 2018). However, this  
699 representation constricts the process to precipitation availability, and does not consider the four natures of  
700 droughts, i.e. meteorological, hydrological, agricultural and socioeconomic. Accordingly, this depiction  
701 might lead to an underestimation of drought risks (Vogt et al., 2018 *in* Tuomenvirta et al. 2019), which in  
702 reality are the most complex weather-related disasters due to their widespread cross-sectoral impacts  
703 (Tuomenvirta et al., 2019). The underestimation of risk will subsequently affect the accuracy of the related  
704 solutions. This can be considered as the starting point for drought NBS-NBaS research.

705 Whether designed for slow or rapid onset climatic events, climate change, the climatic characteristic of the  
706 concerned setting, and the frequency and intensity of extreme weather events are very susceptible of  
707 reducing the efficiency of NBS-NBaS (Gomez Martin et al., 2019). Climate change also influences the  
708 benefits and trade-offs provided by these solutions (Gomez Martin et al., 2019). To consolidate this fact,  
709 the following examples are given

710 - Climate characteristics: Small natural water retention features showed considerable potential in the UK,  
711 but had very reduced efficiency in Mediterranean contexts (Douglas et al., 2019). This is due to the  
712 differences of rainfall intensities that require a greater number of retention measures in the Mediterranean  
713 climatic regime (Douglas et al., 2019). In cold climates, the efficiency of edible solutions is questionable  
714 since they won't be able to deliver their service around the year (Wubben et al., 2020) due to plant growth  
715 factors.

716 - Seasonal variations: A spatio-temporal variation in the capacity of NBS-NBaS to provide ecosystem  
717 services can be observed in several cases (Fletcher et al., 2020). Per example, solutions based on broad  
718 leaved trees can become relatively inefficient during autumn and winter as they shed their leaves (seasonal

719 variation of ecoservices provision). In climates where evapotranspiration fluctuates throughout the seasons,  
720 the flood volume reduction capacity of green solutions will equally vary (Fletcher et al., 2020). Other NBS-  
721 NBaS used to reduce incoming solar radiation on buildings will fulfill their functions in summer, but might  
722 cause increases in heating loads during winter (Canton et al. 2001 in Bailly et al., 2019a).

723 - Extreme weather events: In summer, an unexpected succession of rapid storms may saturate water storage  
724 capacity much faster than the solutions' evapotranspiration rates, hence overpowering the NBS-NBaS  
725 (Fletcher et al., 2020). Similarly, increasing rainfall return periods can reduce the effectiveness of green  
726 roofs, pervious pavements, bio-retention elements and rain gardens (Majidi et al., 2019).

### 727 **3.6.2. Risks of oversimplification**

728 In the words of Albert Einstein, "Everything should be made as simple as possible, but not simpler". One  
729 of the strongest points of the NBS-NBaS concept is its relative simplicity that makes it widespread and  
730 more or less grasped by a large audience. In this vein, O'Sullivan et al. (2020) report that in current NBS  
731 literature, a discussion of what forms the N of NBS-NBaS is still missing. According to the same Authors,  
732 it is unclear if nature only refers to biotic components, or also includes the abiotic factors and their effect  
733 on biotic ones. This may be due to the fact that "nature" in NBS-NBaS is defined and interpreted according  
734 to the viewer's background or discipline (CER et al., 2018). Most commonly, it seems that actual nature  
735 (ecological resources, processes, and feedback loops) is undervalued, with most of the discourse focusing  
736 on nature's positive socioeconomic outcomes (O'Sullivan et al., 2020). This narrow focus on benefits  
737 makes NBS and NBaS utilitarian anthropocentric concepts according to Nature4Cities (CER et al., 2018).  
738 While in reality, these concepts encompass complex processes that include different components of the  
739 geosphere, hydrosphere, atmosphere and a range of ecosystems (Kumar et al., 2019).

740 In terms of NBaS, not only is nature undervalued, but their potential for reducing climate vulnerability and  
741 promoting sustainability is also oversold (O'Sullivan et al., 2020). According to Sekulova and Anguelovski  
742 (2017) in O'Sullivan et al. (2020), nature is romanticized and overestimated to the point where the concepts  
743 of NBS-NBaS risk becoming unscientific (O'Sullivan et al., 2020). The same Authors provide a "dose of  
744 reality" through a literature discussion of the current perspectives on nature using five references; the most  
745 important elements to retain are:

746 In terms of NBaS: Nature is being represented as a green injection primarily into cities (Kaika, 2017 in  
747 O'Sullivan et al. 2020) to help governments make citizens immune to climate change (Esposito, 2013 in  
748 O'Sullivan et al., 2020).

749 In terms of NBS and NBaS: The drive for green and blue spaces is not environmental nor scientific, but is  
750 rather economic, i.e. growth obsession (Kabisch et al., 2016 in O'Sullivan et al. 2020). According to  
751 Sekulova and Anguelovski (2017) in O'Sullivan et al. (2020), the environmental angle will almost always  
752 lose at the expense of the socioeconomic goals. This might be due to three reasons:

753 i. Emerging literature on urban NBS-NBaS deals mostly with the ecological, socio-cultural and  
754 economic dimensions (Veerkamp et al., 2018). The integration of "harder science" insights is still  
755 lacking and can be considered as an important line of research to develop. Hence, one might consider  
756 that there is a lack of ready-to-apply scientific knowledge (Egusquiza et al., 2017).

757 ii. The IUCN labels challenges that NBS-NBaS respond to as societal challenges. This nomenclature  
758 can be assumed to be logical as these arise from a combination of natural and anthropogenic causes  
759 (Balzan et al., 2020). However, this indirectly undermines the scientific background of these  
760 challenges and gives NBS-NBaS a more "practical" nature. This simplification may be beneficial for  
761 spreading the concepts across different target groups, but risks oversimplifying the underlying science  
762 behind the challenges, the solutions and the intended outcomes.

763           iii. Environmental challenges are marked by complexity, uncertainty, large spatio-temporal variability  
764           and often irreversibility (van den Hove, 2000 *in* Fohlnesiter et al., 2019). These elements are  
765           particularly amplified in the case of climate change, hence the increased difficulty of NBaS compared  
766           to NBS. The latter rely largely on the ecosystem service concept in which also insufficient scientific  
767           basis coupled to the inconsideration of nature’s intrinsic value are major weak points (Bull et al.,  
768           2016). For NBaS, the same principles apply in addition to the layers of complexity brought about by  
769           the introduction of the already uncertain and complex climate change.

770           If the environmental dimension and science(s) behind NBS-NBaS remain underdeveloped as the concept  
771           favors its practical and economic sides, NBS-NBaS risk being lost as buzzwords. To overcome these  
772           barriers, significant research efforts are required along with long term visions of resilience (particularly for  
773           climate change), instead of short-term research on quality (Bailly et al., 2019a). At this stage, the cross-  
774           sectoral nature of NBS-NBaS might be a helpful factor, yet current efforts are compartmentalized (silo  
775           approaches), and the concerned disciplines have very limited interactions with each other (Maksimovic et  
776           al., 2021). Even when solid knowledge exists, it is often scattered across different disciplines (Bulkeley and  
777           Raven, 2018).

### 778           **3.6.3. System complexity**

779           Addressing NBS and to a certain extent NBaS, from the EC’s perspective requires a complex interplay  
780           between definitions, challenges and sought solutions (Morello et al., 2018)..

781           A solid understanding of nature’s and systems’ complexity is needed for successfully designing NBS-NBaS  
782           (Schmalzbauer, 2018). This element is currently one the major gaps for upscaling NBS-NBaS (Ruangpan  
783           et al., 2020). Once integrated, this understanding can help in complementing the effort of actors of various  
784           backgrounds (including ordinary citizens) to ensure the success of any designed/implemented solution.

785           Whether of small or large scale, the introduction of NBS-NBaS into an already existing (eco)system implies  
786           the introduction of new nature processes that are often complex and interdependent (Debele et al., 2019).  
787           Nearly all the retained projects acknowledge this state and call for adopting complex thinking. The latter is  
788           necessary for dealing with the associated uncertainties and risks (Morin 2014 *in* Bailly et al. 2019b), as it  
789           also allows to draw attention to the undesirable effects (disservices) that may be brought about (Bailly et  
790           al., 2019b). Within the retained projects complexity is addressed in both theoretical and technical angles.  
791           The most pronounced aspect of theoretical complexity stems from the targeted environmental challenges,  
792           namely climate change and hydrometeorological risk reduction. In terms of CCA, both climate change and  
793           adaptation are complex entwined elements. In terms of hydrometeorological risks, the combined  
794           meteorological and hydrological processes that give rise to a certain event (hazard) create a layer of  
795           considerable complexity to consider (Debele et al., 2019). Moreover, hydrometeorological hazards are also  
796           capable of occurring simultaneously, in a cascading manner or even additively (Aguzzi et al., 2019). This  
797           means that a multitude of factors can interfere hence compounding complexities.

798           In terms of technical and fundamental knowledge on NBaS, the different projects acknowledge that some  
799           solutions are more complex than others, and thus require different approaches. For example, reconnecting  
800           floodplains (along with the involved hydrological, geomorphological and pedological processes and  
801           knowledge) is much more complex than designing allotment gardens (Somarakis et al., 2019). Similarly,  
802           some solutions are less difficult to grasp given their relative simplicity and their direct tangible effects. For  
803           instance, as highlighted in proGReg, urban farming delivers edible products in a relatively fair amount of  
804           time, making it simpler and more lucrative than green roofs that provide less tangible effects, and require  
805           extensive expert [scientific and technical knowledge] (Wilk et al., 2020). On the implementation side,  
806           Saraco et al. (2020b) revealed that during their project, the implementation phase was longer and harder  
807           than originally planned. This operational complexity is often a significant hurdle that complicates the  
808           dialogue between the different concerned actors and can even be a backdrop for a given plan.

809 While most of the theoretical and technical difficulties can be resolved through the introduction of more  
810 knowledge, several limits and gaps should be addressed:

811 - The complexity of the environmental challenges and the solutions themselves calls for significant efforts  
812 that are still somewhat underdeveloped, particularly in the domain of assessing the changes brought about  
813 by the (re)introduction of “nature” and its processes into a specific ecosystem. Accordingly, there is a need  
814 to develop tools that take into consideration the interconnectivity of the natural and newly inserted system  
815 (Altamirano et al., 2020). This aspect calls for better understanding of ecological dynamics, in which often  
816 a particular’s system equilibrium comes from the dynamic interactions of factors that result in zero net  
817 entropy. While understanding this equilibrium and its components might be a difficult task, it certainly  
818 forms an important line of research to develop.

819 - Solutions that target the links between stressors, driving forces and causal factors, while addressing  
820 adaptation at different spatial and temporal scales are particularly required for addressing multi-hazard  
821 approaches (i.e. multipurpose NBaS and/or NBaS for DRR).

#### 822 **3.6.4. Uncertainty**

823 Addressing multi-faceted solutions such as NBS-NBaS requires the consideration of complexity,  
824 redundancy and associated uncertainty particularly through different scales (Egusquiza et al., 2017). A  
825 chain of uncertainties associated with NBS-NBaS can be observed throughout the different projects:

826 - The starting point of uncertainties in NBS-NBaS is the dynamic and complex nature of the challenges  
827 these respond to (Somarakis et al., 2019), namely climate change.

828 - The second point comes from the unpredictability and uncertainty of the nature (NBaS) “base” itself  
829 (Somarakis et al., 2019). Linked to that point are two facts: i) under the natural hazard scope, nature is  
830 perceived by people as an unstable element that might generate catastrophic events, accordingly, the use of  
831 nature under the form of NBS-NBaS to reduce risks raises some skepticism (Chou, 2016 in Han and  
832 Kuhlicke, 2019). ii) NBS-NBaS build on ecosystem functions and services, which in turn are dynamic,  
833 uncertain and evolve over time often in non-linear manners (Somarakis et al., 2019).

834 - The use of NBS as tools for CCA is still relatively recent and not very widespread due to underlying  
835 conservatism (Kuban et al., 2019). The latter might be due to lack of knowledge that creates a fear of  
836 the unknown (Solheim et al., 2021) that subsequently propagates across the various elements of the NBS-  
837 NBaS chain (design, implementation, operationalization, etc.). According to the NAIAD and UNaLab  
838 projects, as NBS-NBaS are still perceived as innovations, their conception as uncertain elements is a source  
839 of risk (Altamirano et al., 2020; Stahlbrost et al., 2018). In this vein, upscaling and mainstreaming NBS-  
840 NBaS become challenged by: i) the difficulty of capturing the value of NBS-NBaS, ii) the lack of  
841 understanding of long-term benefits and iii) the uncertainties due to the disconnection between short-term  
842 actions and long-term goals (Perrin, 2018).

843 - Adaptation is often challenged by the absence of decisive metrics. Therefore, measuring adaptation is an  
844 uncertainty barrier to overcome for NBaS. To this end, when adaptation is questionably calculated, NBaS  
845 are inaccurately designed, and uncertainties for quantifying climate resilience increase since the latter is the  
846 sum of CCA and CCM actions.

#### 847 **3.6.5. The scale quandary**

848 Most H2020 NBaS projects are demonstration projects that often target small or specific pilot scales (except  
849 for OPERANDUM, PHUSICOS, RECONNECT, FutureMARES and PONDERFUL). With the global spread  
850 of NBS around the world, European pilot-sites and cluster projects intervention are making Europe stand  
851 out as the world NBS leader (CLEVER Cities, 2021). Per example, living labs are much addressed  
852 throughout different projects, namely those that concern the urban medium (Wilk et al., 2020). In these



853 units, economic/technological methods and concepts are developed and put to the test in a small real-life  
854 context (Wilk et al., 2020). It is believed that the diversity of size and scales of the pilot sites facilitates the  
855 extrapolation of findings to bigger scales having similar climatic properties (Boskovic et al., 2021).  
856 However, despite their importance, demonstration projects only generate applied and site-specific  
857 knowledge (Xie et al., 2020) and are often practical variations of earlier research (Strout et al., 2021). This  
858 recurrently makes of them NBS-NBaS awareness raising projects (Altamirano et al., 2020), rather than  
859 knowledge generating elements. This might be due to the site-specific nature of NBS-NBaS that  
860 complicates the generation or communication of “harder” aspects of knowledge (Xie et al., 2020), or to the  
861 oversimplification of the concept as discussed in the previous section.

862 Regardless of the type of knowledge generated, the narrow focus on specific scales (mostly pilot site  
863 interventions that do not extend beyond a plot, district or neighborhood scale or plot, tributary, sub-basin)  
864 makes the identified limitations, achieved successes and the methods developed not necessarily applicable  
865 or replicable at both finer or larger scales (Somarakis et al., 2019). In this vein, upscaling to larger scales  
866 (i.e. greater than pilot sites) is a significant challenge for scientists and researchers, as the knowledge and  
867 methods utilized in pilot sites may not be applicable at larger scales (von Wirth et al., 2019 *in* Schmalzbauer,  
868 2018). In addition, the requirements for much more resources and the buy-in of powerful actors add another  
869 layer of difficulty.

870 Moreover, the scales used by the research community do not always match those of planners (Knaus and  
871 Haase, 2020). This scale mismatch poses direct barriers to knowledge transfer and researcher-practitioner  
872 contact (Knaus and Haase, 2020). While the pilot scale approach is very important, NBS should be  
873 considered beyond their local effects, must be connected and should have a multi-scalar nature (Bailly et  
874 al., 2019a), i.e. they should be studied across and through different scales. To that end, there is a pronounced  
875 gap in the amount of research on small scale (e.g. urban) and large scale (e.g. catchment or regional) NBS  
876 (Ruangpan et al., 2020). Currently, the implementation of NBS-NBaS at large scales is limited, and is rather  
877 restricted to pilot site interventions of limited sizes (Altamirano et al., 2020). The complexity of larger  
878 systems might be a valid underlying reason, however this disconnection between scales is a significant  
879 hurdle for upscaling (Ruangpan et al., 2020). The lack of experience in large scale ecosystem restoration  
880 practices (Banwart et al., 2019, 2018) may also be a contributing factor.

881 In the case of NBS-NBaS for DRR, particularly hydrometeorological hazard reduction, implementation is  
882 often at small-scale, and hence with a negligible effect on large hazards (Kumar et al., 2019). Expecting  
883 from a single NBaS to reduce risks and damage costs, as well as provide a quantum leap in resilience might  
884 be too ambitious. Per example, punctual/local stormwater management solutions aren't as effective as  
885 watershed scale NBS-NBaS that buffer peak runoff and flooding risks in the whole spatial unit including  
886 the target area (Somarakis et al., 2019). However, relevant evidence and knowledge are still somewhat  
887 limited when NBS-NBaS are part of a larger hydrological system (Ruangpan et al., 2020 *in* Solheim et al.,  
888 2021; Turconi et al., 2020; van Soesbergen and Mulligan, 2018). The same applies for watershed scale  
889 hybrid solutions that contain both small size or large sized NBS-NBaS (Watkin et al., 2019). As a result of  
890 these factors, most risk assessments target small scales (local to regional approaches) often leaving out the  
891 larger matrix (Renaud et al., 2019). Consequently, large scale NBS for hydrometeorological risk reduction  
892 are left out of the picture as the spatial unit of assessment disregards them. Therefore, these solutions are  
893 still in serious need for further studies particularly in European reference frameworks (Vojinovic et al.,  
894 2019). This knowledge gap can be considered as a major bottleneck for holistic risk management and  
895 resilience plans where large scale NBS-NBaS interventions are often needed (Somarakis et al., 2019).

896 In the case of NBS for climate resilience (i.e. NBaS and NBS for CCM), the difference of scales is also a  
897 complex factor. Generally, these type of solutions call for two scales: for mitigation, solutions are sought  
898 at macro scales while adaptation solutions target the meso and micro scales (CAR et al., 2017; GMV et al.,  
899 2018). However, other Authors believe the opposite and stress that adaptation plans and actions should  
900 target the landscape or wider scales to account for all the interactions of the concerned ecosystems (Kapos

901 et al. (2019) *in* Altamirano et al. 2020). Yet different climatic challenges also require different scales and  
902 that itself is an additional barrier. For instance, NBaS for UHI reduction require a city scale approach,  
903 pluvial flooding requires an urban zone scale intervention, while river flooding requires a watershed scale  
904 approach (Somarakis et al., 2019). Arguably, evidence of small scale interventions is more or less  
905 established, however similarly to NBS for DRR, evidence of efficiency is particularly lacking at large scales  
906 (landscape or watershed). As the concerned challenges are often multi-scalar, the difficulty of measuring  
907 the solutions' multi-benefits and efficiency increases (Davis et al., 2018). To this end, sufficient best  
908 practices in different settings are still lacking (Knoblauch et al., 2019) and significant research efforts are  
909 still needed.

### 910 **3.6.6. Measuring progress and monitoring NBaS**

911 The efficiency and the success of a solution are generally measured after its implementation by determining  
912 the changes between its pre and post existence phases. However, a solid base on NBS evidence is still  
913 lacking in scientific literature (Douglas et al., 2019). NBaS also still lack well-established proof of their  
914 effectiveness for CCA/CCM, especially in relation to the achievement of their set targets (CAR et al., 2019).  
915 Accordingly, NBaS are still in a state of unknown performance (CAR et al., 2019). In this vein, research  
916 efforts yielded many evidence of climate change, yet no conclusive evidence of NBS-NBaS benefits,  
917 performance and functionalities is established (Bailly et al., 2019a). The same also applies in the domain  
918 of NBS-NBaS for hydrometeorological hazards (Debele et al., 2019).

919 In response to this state, current research on NBS is focusing on finding/building indicators for providing  
920 conclusive evidence on the efficiency of these solutions (Collier, 2021). However, this line of research is  
921 still somewhat embryonic, and further efforts are needed (Somarakis et al., 2019). Under the H2020  
922 projects, a multitude of monitoring and assessment frameworks, and a plethora of indicators are used and  
923 presented (namely MAES, UNaLab, NATURVATION, EKLIPSE and others). Most projects use the  
924 EKLIPSE framework (Raymond et al., 2017), while others develop their own assessment frameworks such  
925 as the projects listed in Table A (refer to Supplementary Material 1).

926 However, there still isn't a commonly accepted or uniform monitoring and evaluation framework  
927 (Schmalzbauer, 2018). Even when monitoring occurs, the length of monitoring period is often short or is  
928 characterized by a low frequency. This may be due to the fact that an unknown amount of time is needed  
929 for a NBS-NBaS to become fully effective (Somarakis et al., 2019). According to Kuban et al. (2019), the  
930 difference of time scales between the short to medium NBS-NBaS interventions, and the long time needed  
931 to unravel their effects makes this type of analysis difficult. In this sense, Garcia Perez et al. (2018) in the  
932 CLEVER Cities project recommend that monitoring and evaluation should go along with the maturity of  
933 the solution, i.e. at least five years post-implementation. Conversely, Holscher et al. (2019) recommend the  
934 integration of monitoring and evaluation as early as the design phase, since the whole NBS-NBaS chain is  
935 loaded with underlying assumptions and uncertainties. Accordingly, the NBS-NBaS monitoring and  
936 evaluation framework should be progressive and continuous, to the point where outcome data following  
937 implementation can become baseline data for the future implementation of other solutions. Following this  
938 logic, NBS-NBaS should be gradually introduced to have a sufficient time period for a detailed and careful  
939 assessment of their efficiency (Albert et al., 2017). This gives a certain degree of flexibility for refinement  
940 throughout the process (Albert et al., 2017) and ensures the gradual success of the solution. Then again, the  
941 question of measuring success is raised by the UNaLab project: what are the acceptable thresholds to  
942 consider the solution as a success and at what scale (Wendling et al., 2019)? This last point is particularly  
943 important since the most significant difficulty for designing a monitoring scheme is to determine the scale  
944 of impact (Wendling et al., 2019). Accordingly, the following questions are also raised: will the  
945 implemented NBS-NBaS have benefits beyond its location? Is it part of a bigger NBS-NBaS network? If  
946 so, how can it be individually assessed within the larger matrix?

947 All of the retained projects contained different sets of Key Performance Indicators (KPIs) for monitoring  
948 and evaluating their implemented solutions. Some projects also address monitoring and evaluation through

949 a modeling and/or impact assessment approaches. The former surpasses the latter with its predictive  
950 capacities (Bulkeley and Raven, 2018) that can provide better insights, namely by comparing pre, peri and  
951 post NBaS phases. They can also serve to project future changes in scenarios (NBaS expansion, climate  
952 change, etc.). However, it is crucial to acknowledge data and model limitations as even the best available  
953 data can hold large uncertainties at different scales (Burke et al., 2018). For instance, engineering models  
954 are not very suitable for tackling NBS-NBaS interventions as the latter are of highly distributed nature  
955 (Burke et al., 2018). Modelling can also be a source of skepticism since it is based on assumptions that are  
956 not necessarily justifiable in real-life cases (Olsson and Andersson, 2006 *in* Kumar et al. 2019). In addition,  
957 over ambition in modeling must be avoided as in some cases, simulations are run on the basis of scenarios  
958 that may never occur (e.g. 100% case of green roofs in an urban setting).

959 NBaS aim to address climatic challenges through specific actions. In turn, each action has an associated set  
960 of awaited impacts that also requires specific array of quantitative indicators related to climate resilience  
961 (Bailly et al., 2019b). To that end, there are still questions concerning: i) the efficiency of NBS-NBaS under  
962 different climatic situations, and ii) how NBS-NBaS accelerate the adaptability of a context (Debele et al.,  
963 2019). As NBS-NBaS require time to mature and become fully effective, the delivery of their co-benefits  
964 can be gradually produced at different time steps (Giordano et al., 2020 *in* Gomez Martin et al. 2019). A  
965 certain co-benefit can decrease the delivery of another, meaning that the overall effectiveness of NBS-  
966 NBaS will also be influenced (Gomez Martin et al., 2019). This issue should also be monitored as the  
967 success of a NBS-NBaS not only depends on the delivery of co-benefits, but also on producing a balance  
968 between them (Gomez Martin et al., 2019).

969 The debate on qualitative versus quantitative assessment is also polarized. While quantitative indicators are  
970 needed to provide solid numerical insights, qualitative indicators are equally needed to provide context-  
971 specific information that often characterize NBS-NBaS (Da Silva et al., 2020). Even if several indicators  
972 of quantitative nature have been built, there's still a call in literature for more robust numerical frameworks  
973 to assess the performance and benefits of existing or newly installed NBS (Watkin et al., 2019). In their  
974 own right, defining qualitative indicators - e.g. measuring well-being - is a challenge, since these can be  
975 subjectively interpreted and lack a straightforward/consistent methodology (Da Silva et al., 2020). This  
976 limitation poses subsequent difficulties for the evaluation of these solutions' efficiency, values and benefits  
977 (Ruangpan et al., 2020). Despite the various efforts of some projects for developing a common indicator  
978 framework (e.g. ThinkNature), measuring intangible values is still a considerable hurdle to overcome  
979 (Schmalzbauer, 2018). For this purpose, significant multi and transdisciplinary approaches are needed  
980 (European Commission, 2021b). However, according to Basta (2021), none of their examined H2020  
981 projects up until 2019 implemented frameworks for evaluating the credibility, relevance and effectiveness  
982 of the knowledge generated or reported during their research phases. This means that there weren't any  
983 uses of systematic monitoring and evaluation for documenting transdisciplinary research or methods (Basta,  
984 2021).

### 985 ***3.6.7. On resilience in the H2020 projects***

986 As can be noticed, the term resilience is present throughout the different sections of the manuscript. It is  
987 often associated with the process of adaptation. However, the resilience-adaptation nexus is quite polarizing  
988 as both can promote and demote each other at the same time (Nelson, 2011). Under the climate change  
989 scope, both concepts show pronounced differences (Leggett, 2021). Generally, climate change response  
990 strategies often require resilience OR adaptation (Wong-Parodi et al., 2015), i.e. a sort of  
991 separation/competition between the two concepts.

992 Adaptation is mainly sought for coping with the implications of climate change, while resilience is sought  
993 for developing the capacity of withstanding the threat. As such, adaptation is a process, while resilience is  
994 a capacity (Leggett, 2021). In the IPCC's definition of resilience, a great deal of importance is given to  
995 the amount of change that a system can withstand, hence relating resilience to coping ranges (Levina and  
996 Tirpak, 2006).

997 Arguably, adaptation helps a system to absorb shocks while resilience helps the system to do so and resume  
998 its functioning (Der Sarkissian et al., 2021). However, no consensus on the resilience-adaptation nexus  
999 exists. This could be due to the fact that adaptation and resilience have emerged from different research  
1000 disciplines (Nelson et al., 2007) and under dissimilar contexts (Nelson, 2011). Nonetheless, one might argue  
1001 that resilience is needed for managing systems in a flexible and adaptive way. Under this context, resilience  
1002 can be considered as a mean to broaden the reach of adaptation, hence the intersection zone between both  
1003 concepts (Nelson et al., 2007).

1004 As climate change is the main scope of the retained projects, climate resilience is addressed as the sum of  
1005 CCM and CCA. The former (i.e. CCM), is usually better quantified since it is related to the reduction of  
1006 emissions and carbon storage or removal. Such indicators are well-established throughout the different  
1007 projects with many metrics for carbon storage/removal capacities of soils and biomass (e.g. UNaLab).  
1008 Conversely, the lack of adaptation targets, metrics, and indicators hinders accurate resilience quantification  
1009 efforts. Moreover, under the NBS-NBaS scope, resilience is often delivered through ecosystem services.  
1010 As mentioned in previous sections, the difficulty of quantifying ecosystem services adds another layer of  
1011 complexity. Certainly, these disparities complicate regional comparisons for evaluating the quality of NBS-  
1012 NBaS beyond the pilot sites they exist in. The site-specific nature of these solutions also prevents cross-  
1013 comparisons. Consequently, the evaluation of NBS-NBaS currently does not extend beyond pilot sites.

1014  
1015 In relation to adaptation pathways, these were created for efficient policymaking in the face of future  
1016 uncertainties. Accordingly, these ensure iterative and flexible approaches that accommodate for climate  
1017 change and its uncertainties. By aggregating adaptation options, assessing their effectiveness and  
1018 sequencing them in the form of pathways, Zorita et al. (2021) indicated that the use of adaptation pathways  
1019 is an efficient method for city or sector levels. Nonetheless, do not extend to higher scales. Therefore, the  
1020 connection of adaptation pathways to resilience trajectories in a multi-scalar feature-space is yet to be  
1021 understood. These observations converge with the recommendations of Cai et al. (2017) for promoting  
1022 further research on multi-scalar resilience.

### 1023 1024 **3.6.8. The other side of the coin: disservices**

1025 One of the main advantages of the NBS framework is that it acknowledges the existence of disservices  
1026 (Schaubroeck, 2017). However, it isn't until recently that disservices became well discussed in NBS  
1027 literature. In terms of NBaS, one of the most perceivable risks is climate gentrification (Kiss et al., 2019).  
1028 Almost all of the retained projects acknowledge their existence and incorporate some related types of  
1029 analysis during their design or planning phases. However, only accounting for disservices is not enough.  
1030 There is an equal need to account for trade-offs particularly when one ecosystem service decreases due to  
1031 an increase of another (Bailly et al., 2019a). In that sense, NBS-NBaS may lead to negative consequences  
1032 on ecosystemic balance (Banwart et al., 2019). It is therefore important to acknowledge that any NBS-  
1033 NBaS can have unexpected or unplanned negative outcomes, for despite their importance, NBS and NBaS  
1034 consume natural resources while they exist (Somarakis et al., 2019). Therefore, one should not assume that  
1035 the NBS-NBaS intervention will surely work (Burke et al., 2018). That is why the risk of failure should  
1036 always be accounted for. Therefore three scenarios are recommended to be expected. The first is a case  
1037 where everything occurs as planned, the second is a best scenario where all expected elements are achieved  
1038 to the maximum, and the third is a critical scenario where failure is expected.

1039 However, according to UNaLab, disservices and risks are often outweighed by the long-term benefits of  
1040 NBS-NBaS (Hawxwell et al., 2018). Nonetheless, this does not mean that disservices are to be treated  
1041 lightly as in some cases these can have serious consequences. For instance, with a changing climate,  
1042 increasing the extent of water bodies might be a serious proliferation factor for water-borne diseases  
1043 (particularly in tropical or equatorial settings). Such considerations need to be made according to the  
1044 reigning climatic regimes. To this end, disregarding disservices during early analysis is a significant threat  
1045 that can amplify risks and lead to efforts in vain (Bailly et al., 2019a).

1046 **4. Conclusion**

1047 In this paper, a thorough analysis of NBaS projects issued from the H2020 program was performed. The  
1048 purpose of this study was to build a scientific state-of-the-art on current knowledge and research needs from  
1049 the analysis of European contributions. For this purpose, 21 out of the retained 27 projects had deliverables  
1050 at the time of this study and thus formed its basis. From a total number of 173 deliverables, 137 were  
1051 retained and analyzed with respect to the scope of this study. In this regard, only environmental and  
1052 biophysical elements were included as this study was concerned more with the fundamental and theoretical  
1053 basis of the concept. Nonetheless, this does not take away any degree of importance from the concept's  
1054 technical, political and socioeconomic aspects. In this vein, one of the main challenges for this study was  
1055 to synthesize and compile knowledge from very different sources as a result of the projects' diverse  
1056 background (different nature and disciplines). This last element prevented drawing clear parallels between  
1057 projects and directly comparing their outcomes even within the same study areas. The different targeted  
1058 contexts, climatic settings, and socioecological characteristics also added another layer of complexity for  
1059 direct comparisons. To account for this factor, an extensive review and in-depth analysis were performed  
1060 to connect the different dots and draw a clear line of work.

1061 The Authors acknowledge the partial descriptive nature of the results. However, the aims of this paper was  
1062 to present a timely inventory of H2020 efforts with a focus on the EU's progress, contribution, and status.  
1063 It can be considered more or less as a roadmap of what has been accomplished/found till now (state-of-the-  
1064 art), with a contribution to develop lines of work that were proposed based on identified limitations and  
1065 gaps. On this basis, the paper can be listed as an effort to provide a comprehensive roadmap for studying  
1066 the ongoing and progressive transition from NBS to NBaS.

1067 While many projects generate/generated substantial amount of knowledge, most of their approaches are  
1068 still demonstration or pilot-site interventions. Accordingly, these often take the form of awareness-raising  
1069 elements rather than knowledge generators. As mentioned previously, the findings of this paper are not  
1070 undebatable as the sample choice and size may induce certain flaws. However, the flaw margin was reduced  
1071 as much as possible by filtering the documents thoroughly and by avoiding assumptions. In what follows  
1072 several relevant recommendations are given:

1073 i. Extending interests beyond the urban ecosystem

1074 The interest of the EC's H2020 program in the urban realm is justifiable. Yet, a deeper approach to other  
1075 ecosystems is much needed. The relative dominance of the urban medium makes most of the knowledge  
1076 generated from the H2020 projects related to these settings. Accordingly, a large proportion of the generated  
1077 knowledge and methods cannot be necessarily generalized to other media. In the same vein, the biased  
1078 focus on urban contexts complicates the identification of NBS-NBaS gaps in other ecosystems. In a given  
1079 way, the current interest in ecosystems is constraining NBS to cities, hence the risks of missing out on their  
1080 potential in other systems.

1081 This is particularly the case of mountainous, forested and marine and coastal environments. While forests  
1082 are very appreciated as NBS-NBaS, they are rarely targeted as a sensitive media to climate change. In its  
1083 own right, the mountainous environment is significantly underrepresented despite its importance and  
1084 relative widespread coverage in Europe. The marine and coastal realms are also underrepresented as both  
1085 a medium and a source of solutions.

1086 ii. Enhancing knowledge on nature (N) in NBS and NBaS

1087 European findings underlined the need to focus more science on the N (nature) behind NBS and NBaS. For  
1088 this purpose, scientific and physical methods are needed to better understand the interaction of nature both  
1089 with and within the implemented or planned NBS-NBaS. However, this does not come as an alternative to  
1090 the concept's practical and socioeconomic nature, but rather as supplement. The rationale behind this logic  
1091 is to have a holistic framework that balances between all the theoretical and fundamental components of

1092 NBS and NBaS. This is due to the fact that the introduction of these solutions into ecosystems causes the  
1093 entry of new systems along with their processes. Yet the investigation of these interactions and their  
1094 cascading effects is still somewhat limited. This gap could be on the most pronounced challenges for  
1095 upscaling and outscaling NBS-NBaS as well as for unlocking their full potential.

1096           iii.       Exploring and developing several lines of research work

1097 Cross-cultural analysis in a global sense, does not appear in the H2020 environment. While community-  
1098 based actions and civil society participation are well accounted for, an analysis of how cultural knowledge  
1099 reconcile with natural ecology and sustainability is not always present. Embedding this approach into a  
1100 global scale environment (beyond a Europe-focused approach) might be worthwhile considering. The  
1101 rationale behind this proposition is that deeper insights on cross-cultural aspects can leverage the use of  
1102 NBS-NBaS by providing inputs to the science-practice-policy sphere. Accordingly, the co-design, co-  
1103 implementation and co-production of solutions are ensured. In this vein, the ARTISAN project, through its  
1104 analysis of international, regional (European) and national (French) efforts is aiming to position each scale  
1105 with respect to other. With the advances of the project, more multi-scalar insights on NBS-NBaS are  
1106 expected.

1107 In terms of European outlooks, according to Davies et al. (2021), the EU's intention to continue investments  
1108 in NBS is still increasing. The same Authors indicated that the recently launched FP9 Horizon Europe  
1109 program (2021-2027) will aim to integrate NBS into areas such as health, bioeconomy and food systems  
1110 with a particular emphasis on climate change. Accordingly, the extension beyond urban ecosystems is  
1111 starting to appear. While climate change remains a central challenge under the Horizon program, the  
1112 transition from NBS to NBaS can still be considered as ongoing. In this vein, studying the intersection  
1113 between this paper's listed projects (ongoing ones), and those launched under FP9 could be an interesting  
1114 platform to consider. According to Davies et al. (2021), both in the EU and beyond, the discourse on NBS-  
1115 NBaS should shift from their representation as "products" to become considered as a "process". In this  
1116 vein, several perspectives can be proposed:

1117 1. It is crucial to understand if NBS-NBaS are being currently designed to withstand weather change and/or  
1118 climate change. In a second step, it is important to determine if these solutions be capable of overpassing  
1119 weather change to then withstand climate change.

1120 2. The labelling of the NBS-NBaS challenges as societal makes the concept tip towards more practice-  
1121 centered orientations rather than knowledge generation or science-focused priorities. Moreover, under any  
1122 context, the definition of the societal/environmental challenge to be targeted by NBS-NBaS should be an  
1123 ongoing process

1124 3. While oversimplification might be attended to by increasing the integration of hard sciences, a solid  
1125 understanding of the complexity of natural systems and their processes is needed. However, a careful  
1126 balance between simplification and complication should always be kept to avoid losing NBaS. The aim of  
1127 this approach is not to make NBS-NBaS limited to experts as one of the concept's strongest points is its  
1128 ability to create a shared vision/language and implicate a broad societal commitment to the design and  
1129 implementation of nature. Yet, oversimplifying the concept can make it a simple buzzword, while  
1130 overcomplicating it can make it lose its acceptance/popularity among the different groups that are needed  
1131 to leverage these solutions.

1132 4. The role of uncertainties in NBS and NBaS should be better accommodated and explored through further  
1133 research (Bailly et al., 2019b; Han and Kuhlicke, 2019; Van der Jagt et al., 2020). The same can be said for  
1134 uncertainties and trade-offs (Kumar et al., 2019). While these are developing lines of work, their current  
1135 acknowledgment under all projects reflects the attainment of an ample awareness level.

1136 5. For the implementation of system scale NBS-NBaS, a leap beyond conservationism is needed. Studying  
1137 a mosaic of existing projects as a large scale NBS-NBaS approach through scale transitions may be a good

1138 start. To this end, large scale NBS-NBaS (when existent) should be treated as aggregated multi-scale small  
1139 NBS-NBaS interventions to attend to their implementation, monitoring and benefit quantification angles.  
1140 It is important to consider that large scales (e.g. watersheds) cover a mosaic of ecosystems. That means that  
1141 different responses to various stimuli (in this study’s case climate change) are to be expected. For this  
1142 purpose, understanding tipping points and thresholds is a must. However, this task is quite complicated and  
1143 is still a major gap in research.

1144 6. For attending to large scale NBS-NBaS (upscaling), as indicators cannot be simply added up or  
1145 extrapolated, connecting the different solutions scattered throughout a large area might be a better idea than  
1146 aggregating small disconnected solutions. The connection between solutions implies a connection of  
1147 ecosystems, which in turn creates various ecotones. This ecotone effect allows a maximization of individual  
1148 efficiencies and multiplies benefits (UNaLab, 2019). To the knowledge of the Authors, tapping the potential  
1149 of NBS-NBaS ecotones hasn’t been dealt with yet in literature, neither have their transitions through  
1150 different scales.

1151 7. Understanding how NBS-NBaS utilize natural resources and nature during their existence is a relatively  
1152 understudied and unexplored line of work.

1153 8. The implementation of new NBS-NBaS in sites may lead to soil disturbance (Connop et al., 2020).  
1154 Accounting for soil as both an ecosystem and a potent solution should be further developed namely for  
1155 flood storage capacities and climate change regulation.

1156 9. Within the urban realm, it is crucial to acknowledge that the city will continue to develop throughout the  
1157 existence of the solutions. Therefore, the parallel evolution of both ecosystems should be further studied in  
1158 order to determine how both influence each other and to orient proper decision making. Tracking the  
1159 parallel evolution (current and future) of both ecosystems and solutions is still a relatively untapped domain  
1160 that deserves further attention.

1161 10. As one NBaS is not sufficient to attend to CCA, the multiplicity of solutions will deliver more  
1162 pronounced effects since these power the necessary interconnections (Bailly et al., 2019b). However, to the  
1163 knowledge of the Authors, measuring the climatic connectivity effect of NBaS is still an untapped domain.

1164 11. Understanding ecosystem tipping points and ecological thresholds is a must. Currently, very few to no  
1165 efforts focus on these central elements.

1166 12. An understanding of the supply and demand of ecosystems and their services in complex  
1167 multidimensional contexts is still limited.

1168 13. A systematic approach to understand how the different systems, i.e. ecosystem-NBS-NBaS, interact  
1169 with and influence each other is still limited. Hence the need to provide a more inclusive and holistic  
1170 evaluation framework for properly understanding combined benefits, co-benefits and disservices

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