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Nature-Based Solutions Tools for Planning Urban Climate Adaptation: State of the Art

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Abstract: Despite the recognized potential of nature-based solutions (NBSs) to support climate adaptation, there are still wide barriers for a wider uptake of such NBS in urban areas. While tailored NBS tools could facilitate and accelerate this process, a comprehensive mapping of their availability and capacity to respond to cities' challenges is missing. This research aims to provide an overview of tools that intend to facilitate the uptake of NBS for urban climate adaptation supporting cities in overcoming their challenges. To do so, this paper (i) presents the results of interviews and workshops with municipal officers and decision-makers from different European cities that identified the challenges they experience with NBS uptake; (ii) selects and reviews NBS tools and (iii) analyzes them on their capacity to address these implementation challenges. Our research revealed four key challenges that municipal officers experience: resources availability; level of expertise, know-how or competence; the institutional setting, and collaborative governance and planning. The results from the tools' review show that existing tools can support overcoming a lack of expertise (31), but, to a smaller extent, can also be of use when experiencing the institutional setting (13), availability of resources (11), and collaborative governance and planning (10) as a challenge. This work provides researchers and tool developers with insights into potential market saturation as well as scarcity of certain types of tools that would match cities' challenges, highlighting needs and opportunities for new tool development.

Keywords: nature-based solutions; green infrastructure; ecosystem services; climate adaptation; sustainable development; cities; tools; uptake; integrated planning; urban planning; review

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1. Introduction

Sustainable development is a challenging task faced by decision-makers worldwide, which has been formalized with the adoption of the UN Sustainable Development Goals in 2016 [1]. These SDGs are of particular relevance at the urban scale, because the underlying issues that call for sustainable urban development and the complexity of addressing these often-intertwined issues are especially apparent for urban planning and decision making [2]. This crucial role of cities for local and global sustainable development is clearly stated in the dedicated urban goal within the UN Sustainable Development Goals (N.11) and in the New Urban Agenda [3] that aims to accelerate its realization. It is also reflected in the various international city initiatives that connect thousands of cities in their ambitions to lead the shift towards sustainable development, such as the "Covenant of Mayors for climate and energy", "ICLEI Local Governments for Sustainability" and the Resilient Cities Network's "1000 Cities Adapt Now" initiative.

Among the main challenges that cities have to face, climate change adaptation is rising as an urgent issue [4]. Cities are of specific interest for their vulnerability to climate change

because the largest share of the world population lives in urban areas and many cities are located in areas that have a high exposure to climate hazards [5,6]. At the same time, climate change impacts such as rising temperatures, heat waves and extreme rainfall events are expected to be experienced most directly by urban populations as the built-environment magnifies climate change effects [7–9]. These impacts will not only differ among cities due to their geographic locations and climate conditions, but also within cities due to microclimate and land-use differences [10]. Urban climate adaptation strategies should then be adaptable and multifunctional in nature because of the uncertainty of local climate impacts and the manifold spatial demands within the urban environment, linked with the environmental, social and economic components of the cities.

Nature-based solutions (NBSs) are increasingly recognized for their potential as an urban climate change adaptation measure and strategy, being multifunctional and solution-oriented by definition, as well as place-based, i.e., adaptable to the specific socio-ecological context at hand [8,11,12]. Given that "nature- based" has a diverse interpretation in the literature [11], it should be noted that we refer to NBSs in line with the definition of the European Commission. They define NBSs 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" [13]. For NBSs to be effective, they require integrated and trans-sectoral planning and governance strategies for their mainstreaming and uptake [11] that involve a wide range of stakeholders and address diverse interests and different perspectives.

By now, the potential of NBSs is being recognized, the interest in NBSs is rising and the benefits and cost-effectiveness of NBSs are increasingly demonstrated in practice [14,15]. Nevertheless, wide uptake in cities still faces significant challenges [16–18]. Some of these challenges include the lack of knowledge and data about the benefits of NBSs; uncertainty around how best to plan, design, implement, and maintain NBSs; financeability of NBSs; the inadequacy of the existing planning system and a lack of openness to collaborative governance that is essential for the successful, place-based implementation of NBSs [16–21].

A large variety of tools have been developed worldwide to support the mainstreaming and uptake of NBSs in cities, ranging from methodologies, software, catalogues, repositories and e-platforms, to guidelines and handbooks. NBS tools can make a valuable contribution in overcoming the barriers that hamper the wide uptake and implementation of NBSs in cities. Tools can, for example, inform and aid the planning processes by selecting and evaluating NBSs, simulating NBS implementation, calculating the costs and benefits of NBSs, supporting stakeholder involvement and facilitating collaborative processes [21–24]. With the EU having set its agenda to implement research and innovation projects on NBSs to create more resilient and sustainable urban areas and societies, various European funded NBS projects (e.g., ThinkNature, EKLIPSE, OPPLA, UNaLAB, UrbanGreenUp, GrowGreen, NATURVATION, Nature4Cities, ClimateKIC ACT on NBS) have been implemented over the past years. As a result, many open-source or licensed tools and databases have been developed to guide the implementation of climate change adaptation measures.

In spite of the potential of NBS tools to support wide uptake of NBSs in cities, there are still gaps and barriers for a wider uptake of such tools by cities and local authorities, thus hampering their contribution to mainstream NBS projects at a local level. End-users can only benefit from these tools when they are aware of their existence, they can compare the diverse available tools, they can make an informed selection of the instruments suitable to address specific challenges in their cities and adapt them to their specific needs and local contexts. To the best of our knowledge, there is not yet such an overview of tools that indicates the suitability of these tools for addressing the various challenge(s) faced in the uptake of NBSs in cities.

The main aim of this research is to better understand in what ways tools that intend to facilitate designing, planning, assessing and implementing of NBSs for climate adaptation

in urban areas can help overcome the uptake of specific NBS challenges that cities are struggling with. Therefore, we (i) researched which challenges cities experience in urban NBS uptake, through structured interviews and workshops with municipalities, and (ii) reviewed tools that intend to facilitate designing, planning, assessing and implementing NBSs in urban areas. The findings regarding end-users' needs and characteristics of currently available tools were then coupled to provide insights into which tools are available for supporting cities in overcoming challenges in NBS uptake.

2. Materials and Methods

This study followed a mixed methodological approach and comprised of three main steps. We conducted semi-structured interviews with municipal officers from eleven European cities and organized two workshops for municipal officers and decision-makers from different EU cities to understand cities' challenges and barriers to uptake NBSs. Secondly, we reviewed NBS tools on their ability to address these challenges as well as on their ability to address specific climate challenges. Finally, these findings were synthesized in a tool catalogue that aims to provide potential end-users not only with an overview of existing tools, but also indicates how these tools can support them to address specific challenges in their cities, neighborhoods and projects. Focusing on European cities, we consulted municipal officers from a variety of European cities and we limited our review to tools and databases that can be used in the European context and are (for the most part) freely and online accessible.

2.1. Consulting Municipal Officers Involved in NBS Uptake

This study used semi-structured interviews and workshops to consult municipal officers involved in NBS uptake in their cities. For the interviews, this study used a purposive sampling selection to gather information from municipal officers with experience in the planning and implementation processes of NBS projects in a variety of European cities. Key representatives from eleven European municipalities—Genova, Savona, La Spezia, Bratislava, Bologna, Torino, Vejle, Milan, Warsaw, Utrecht, and Amsterdam—were interviewed (in the period of September 2019 to January 2020) using a semi-structured questionnaire. The questions focused on the main barriers for NBS uptake, the role and application of NBS tools, and the preferred output that cities would like to see from NBS tools during the various phases from planning to implementing NBSs. The interviews were mainly held in English language, with the exception of some interviews with municipal officers that were held in their local language to facilitate communication. The transcriptions of these interviews were translated into English for the analysis. By analyzing the responses, we endeavored to identify and explore critical elements for the selection and application of NBS tools, to direct the review of NBS tools.

Two workshops were organized in order to use the outcomes as primary data for this study, with a total of 52 participants. In both workshops, participants shared information on their use of tools and their experiences on the planning and implementation of NBSs in local projects. Likewise, they shared information about the barriers they experience for NBS uptake and they indicated how NBS tools could help to overcome such challenges. The first workshop was held in June 2019, at the Nature of Cities (TNOC) Summit in Paris. International and European participants (leaders from communities of practice, policy, and academia) contributed to the seed session on "Planning for Nature-Based Climate Adaptation". The second workshop was held online in June 2020, under the ACT on NBS project framework. During this virtual workshop, "Radically Upscaling Nature-Based Solutions", municipal officers and decision-makers from 15 different EU cities contributed to the break-out session on "Tools for Implementing Nature-Based Solutions". The results from the interviews and workshops were synthesized into an overview of key challenges for NBS uptake, including means to overcome these challenges.

2.2. Review of Tools That Support NBS Uptake

2.2.1. Tools Collection

To examine the ways in which NBS tools can be used to help overcome challenges for NBS uptake, the first step was to compose an overview of relevant NBS tools. NBS tools were identified through: (i) aforementioned interviews with EU municipalities and workshops on NBS tools, and (ii) additional desk research, as further detailed below.

The desk study entailed a combination of reviewing the websites from EU granted projects related to cities dealing with NBSs, ecosystem services (ESs), green infrastructure, urban resilience and climate change, and reviewing peer-reviewed scientific journals, reports and grey literature. The latter search was implemented through Google search, Google scholar and Scopus in August 2020, implying that only tools were collected that were developed and published before that date. The search strategy was implemented using combinations of search terms such as: nature-based solutions, NBS, ecosystem-based adaptation, green infrastructure, climate adaptation, climate resilience, ecosystem services, climate hazards, urban biodiversity, urban nature, water and land management "AND" urban areas, cities "AND" tools, software, methodology, catalogue, repository, platform, handbook and guideline. This research resulted in an initial sample of 70 relevant tools. Subsequently, these tools were evaluated in-depth on their suitability in answering our research questions. That is, only tools were included in our final sample that adhered to the following criteria:

1. a "tool" is understood to be either a methodology, software, catalogue, repository, e-platform, guideline or handbook;
2. the tool can be used to support NBS uptake in the urban environment;
3. climate adaptation lies within the thematic scope of the tool (besides potential other thematic foci);
4. the tool is readily available (i.e., not under development).

2.2.2. Analysis of the Tools

The next step in the review process was labelling and analyzing the final sample of tools on their descriptive characteristics and potential fields of application. Whereas primarily qualitative descriptions were used for the first type of characteristics, the potential field of application was demarcated using fixed indicators (see Table 1). The use of pre-defined indicators was chosen to support the characterization of the tools and to allow for their comparison. The categories and indicators listed in Table 1 were formulated based on the current literature [25–27] and refined through expert judgements. The indicators were also, in some cases, further adapted through an iterative process of tools' analysis. We used tabulation to synthesize our findings into a tool catalogue that summarizes the analysis of the reviewed tools. Finally, we analyzed the potential of the tools to overcome the challenges in NBS uptake, using four indicators identified through the interviews and workshops.

Table 1. Data extracted for the collected NBS tools.

Characteristic	Categories	Description	Indicators
I. Description	Nr. in database	ID of the tool.	Unique number
	Name	Name of the tool.	Name of the tool
	Acronym	Acronym of the tool, if applicable.	Acronym
	Project and owners/developers	Project in which the tool is developed, if applicable, and owners or developers of the tool.	Explanation
	Website	Main web address where the tool can be found or is described.	Weblink

Table 1. *Cont.*

Characteristic	Categories	Description	Indicators
	Strong points	Qualitative description of key strong points.	Explanation
	Scope and Limitations	Scope and main limitations for application of the tool.	Explanation
	Language	Languages in which a tool is available.	English, Dutch/Flemish, French, Spanish, Italian, other
	Type of resource	Characterization of the type of resource.	Software, methodology, catalogue, repository, e-platform, handbook/guideline
	Accessibility	Indication of type of access and use of the tool.	Free and open source, commercial, registration needed
	Type of data provided	Type of data that is provided by the tool.	Qualitative data, quantitative data, spatial data, not applicable
II. Application	Type of information provided	Characterization of the information provided by the tool.	Spatial information, economic information, social information, environmental information, climate information
	Climate hazards	Climate and related natural hazards that are addressed by the tool.	Heavy rainfall, flooding, drought, heat waves, cold waves, landslides, wildfires, sea level rise, all, not found
	Co-benefits	Co-benefits that are addressed by the tool, next to climate adaptation.	Nature and biodiversity, urban agriculture, air quality, energy, socio-economic development, recreation, noise reduction, health and wellbeing, housing
	Planning perspective	The perspective from which a tool can be used. This is related to the disciplines involved in the planning and implementation of NBS.	Spatial planning, financial planning, environmental planning, governance
	Purpose	Purpose for which a tool can be used.	Analytical, planning and design, informative, inspirational
	Phase of use	The phase in the process which a tool can be used: from the early exploration phase (for research and awareness); planning and design in the preparation phase; installation, initial and full implementation until the sustainment phase (monitoring, evaluation, scale-up).	Exploration phase, preparation phase, implementation phase, sustainment phase
	Spatial scale	The spatial scale of application for which a tool has been developed.	Country, province-region, city, district, neighborhood, street, project
	Target group (end-users)	The target group or end-users for which a tool has been developed.	Decision-makers, academics, citizens, public officers, real estate, private sector, consultants, professionals *
	Known past applications	Locations where the tool has been applied.	Africa, America, Asia, Europe, Oceania and, if applicable, explanation for case study countries and cities/regions

In the case of categories that have pre-defined indicators, multiple indicators may apply for one tool; * professionals refers to urban designers, urban planners, landscape architects, artists, urban ecologists, civil engineers, water managers, etc.

3. Results and Discussion

3.1. Urban NBS Uptake Challenges and Needs

Based on the interviews and workshops, we identified four key challenges that municipal officers experience with NBS implementation: the institutional setting; availability of (financial) resources; level of expertise, know-how or competence; and collaborative governance and planning. It should be noted that interviewees (Amsterdam, Bologna, Bratislava, Genova, La Spezia, Milan, Savona, Torino, Utrecht, Vejle, and Warsaw munic-

ipal officers, ACT on NBS interviews, September 2019 to January 2020) and workshop participants (Amsterdam, Bologna, Bratislava, Genova, La Spezia, Milan, Savona, Torino, Utrecht, Vejle, and Warsaw municipal officers, ACT on NBS interviews, September 2019 to January 2020) that contributed to this research are already to various degrees familiar with NBSs and involved in climate adaptation planning, and therefore already have a certain level of access to knowledge and data. However, officers who are not familiar yet may experience other challenges. This also may explain why challenges such as a lack of awareness about environmental problems, their impacts and their solutions [17,21] were not brought forward in the interviews and workshops.

3.1.1. The Institutional Setting

The first challenge that was identified concerns the institutional setting. In various cities, municipal officers experience a lack of awareness or urgency by politicians on the need for and the possibilities for NBSs. Interviewees and workshop participants indicated that, as NBSs can address a variety of adaptation challenges, institutional responsibility for NBSs is typically shared between multiple departments, which can make the development, decision-making and implementation processes more time-consuming and precarious. Politicians and government officials on various levels need to be convinced about the importance of NBSs, their potential, and about the urgency to take action now. These findings are in line with other desk research, which also highlights that a lack of political support is experienced as a challenge for NBS uptake [21]. A related issue expressed in an interview (Vejle, 2019) and in both workshops (TNOC workshop, 2019 and ACTonNBS workshop, 2020—La Spezia, Lakatamia, Madrid, Nicosia, Strovolos, Torino, and Valladolid) is that political continuity can be lacking because of local government structural changes or periodic local elections, and long-term thinking (which is crucial when working with natural systems) may not always be in the interest of politicians. Workshop participants (TNOC workshop, 2019) furthermore expressed that existing regulatory and legal conditions and restrictions, designed for traditional grey infrastructure, can unnecessarily hamper NBS uptake and that administrative procedures are deemed long and complex. The lack of enabling institutional, regulatory and legal frameworks have also been stressed by other studies [17,18,20,28]. Tools that provide examples of successful NBS applications and those concerned with NBS valuation could be instrumental to convince politicians to take action with NBS and to demonstrate that "we can do it and it is easy and cheaper" (ACTonNBS workshop, 2020—Torino).

3.1.2. Availability of (Financial) Resources

Second, the availability of (financial) resources can hamper NBS uptake. Various interviewees (Genova, Savona, Torino, 2019) and workshop participants (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Bologna, Milan and Vejle) indicated that there is a lack of funding or limited budget for the realization of NBSs. Other studies have also identified lack of finance and investment and the financeability of NBSs as a key barrier to the uptake and mainstreaming of NBSs [16,18,20,21]. In addition, a lack of space or a limited amount of publicly owned space or land was mentioned as a barrier by some interviewees (Bratislava, Milan, Torino, and Warsaw, 2019) and workshop participants (ACTonNBS workshop, 2020—Bologna, Milan, Valladolid, and Vejle). When space is privately owned, the influence of the city on whether and where NBSs are implemented is limited, which challenges NBS uptake [28]. To overcome the lack of financial resources, interviewees (Genova, Savona, and Torino, 2019) and workshop participants (ACTonNBS workshop 2020—Bologna, Lakatamia, Milan, Nicosia, Strovolos, and Vejle) indicated that they require capital, or at least knowledge or guidance on how to build the business case for NBSs and obtain financing. Tools that focus on the valuation and financial aspects of NBSs could be helpful in providing this knowledge. In particular, tools that provide insight into the (long-term) costs and NBS benefits, also expressing, for example, livability, aesthetic value, and biodiversity in monetary value, could be helpful.

3.1.3. Level of Expertise, Know-How or Competence

A third challenge is the level of expertise, know-how or competence by some of the involved parties. The lack of education and essential technical skills was mentioned in the interviews (Genova, La Spezia, Milan, and Utrecht, 2019) and workshops (TNOC workshop, 2019 and ACTonNBS workshop, 2020—La Spezia, Lakatamia, Nicosia, Strovolos, and Torino) as a barrier for the mainstreaming and uptake of NBS, which is in line with earlier research that identified the lack of capacity and knowledgeable and skilled professionals as a challenge [17,21,28]. Additionally, citizens' "green" knowledge, behaviour and values was expressed as requiring attention. Furthermore, workshop participants (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Lakatamia, Nicosia, Strovolos, and Torino) deemed it challenging to change the way people are used to working; for example, to deviate from the materials they are used to working with. Workshop participants (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Lakatamia, Nicosia, Strovolos, and Valladolid) furthermore indicated that they need evidence for site-specific implementation, and there is no clear overview of the costs and benefits of NBSs, or the costs of damage when no climate action is taken. Indeed, insufficient knowledge of the effectiveness of NBSs is known to be a challenge [17,21]. To address a lack of expertise, know-how or competence, interviewees (Savona, Torino, Utrecht, Warsaw, 2019 and Amsterdam, 2020) and workshop participants (TNOC workshop, 2019 and ACTonNBS workshop 2020—Bologna, Lakatamia, Madrid, Nicosia, and Strovolos) stated that a catalogue of applicable and customizable solutions could provide cities with more knowledge on measures in general, and specific knowledge on NBSs for particular challenges. Cities also specifically express a demand for knowledge on how to plan and design NBSs. Whereas some cities expressed a need for tools that provide concrete design support and guidance on methodologies to plan green areas, other cities indicated they would prefer a larger, holistic approach. For this, tools could provide inspiration for strategic planners to incorporate NBSs on a larger scale; for example, by sharing experiences from implementing NBSs in practice. Some cities explicitly seek knowledge on the effectiveness of measures in terms of ecosystem services. For this, tools can provide concrete outputs on the effectiveness of measures such as effects of NBSs on city resilience, mitigating impacts of climate change and on reducing heat waves.

3.1.4. Collaborative Governance and Planning

As a fourth challenge, we identified collaborative governance and planning, which is essential for successful, place-based implementation, mainstreaming and uptake of NBSs. During the interviews (Milan and Utrecht, 2019) and workshops (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Bologna, La Spezia and Valladolid), participants named the collaboration that is needed with different areas of the same city council, such as the urban planning, environmental and innovation departments, as a challenge. Many people from inside and outside the municipal organization are involved in NBS uptake and this makes it, for example, difficult to select locations for NBSs—as there are many opinions to be considered and many local considerations to be taken into account. Other research has highlighted that "it is paramount that different departments within the city are involved and informed when a nature-based solution is discussed, shaped and planned" [19]. Additionally, both public and private interests have to be accommodated, whilst public involvement and perception also have to be accounted for. Various studies support the observed challenges, and underscore that the required stakeholder involvement and associated collaborative governance and planning approaches are hampered by traditional planning systems and siloed governance structures [17,20,28]. With regard to the challenge collaborative governance and planning, the interviewees (Milan, Utrecht, 2019 and Amsterdam, 2020) and workshop participants (TNOC workshop, 2019 and ACTonNBS workshop, 2020—La Spezia, Lakatamia, Nicosia, Strovolos, Valladolid) indicated that extending the time for decision making could be beneficial for NBS uptake and mainstreaming. Moreover, close contact between the different departments involved is crucial, and so is involving stakeholders in a participatory process to increase the discussion. Cities indicated that

tools can empower local stakeholders and that tools for engagement, involvement and co-creation are needed. Such tools should facilitate the integration of local knowledge, for example, of the social context. In line with this, it was mentioned that the outputs that a tool provides should be accessible for everyone. One of the cities interviewed (Milan, 2019) also mentioned that tools could help towards mainstreaming solutions and help departments work together rather than working in silos.

3.1.5. Requirements for Effective Application of NBS Tools

Finally, not only the potential of using tools was highlighted in the interviews and workshops, but respondents and participants also indicated challenges and needs that indicate requirements for the effective selection and application of tools to support NBS uptake. Responses from the interviews (Genova, Milan, Utrecht, 2019 and Amsterdam, 2020) and workshops (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Bologna, Lakatamia, Nicosia, Strovolos, Torino, and Valladolid) indicated that there is not just one intended user (group) nor one specific part of the NBS uptake process that should be supported by tools. Rather, there are different potential end-users—such as urban ecologists, planning departments of municipalities, local government, designers, and engineers. When asked what part of the implementation process should be supported by tools, the interviewees (Genova, Milan, Savona, Utrecht, 2019 and Amsterdam, 2020) and workshop participants (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Bologna, Lakatamia, Nicosia, Strovolos, Valladolid) mentioned risk assessment, baseline assessment and opportunity mapping; strategic plan development for larger areas; NBS planning and design, specifically together with civilians and stakeholders; implementation of NBSs, including tools to facilitate communication between different stakeholders during implementation, maintenance and impact analysis. It was also expressed by some workshop participants (TNOC workshop, 2019) that the language in which a tool is provided can be a barrier or an enabler to use certain NBS tools. If tools are in English, potentially a higher number of end-users can make use of the tools. However, in all cases that a tool is not provided in the native language, some officers are likely to face a language barrier. Another challenge is that there are many tools available; which one is the best to use? According to some interviewees (Milan, Utrecht, 2019 and Amsterdam, 2020) it was considered challenging to find and select the proper tools that correspond with local needs and priorities. Other workshop participants (TNOC workshop, 2019 and ACTonNBS workshop, 2020—Bologna, Lakatamia, Madrid, Milan, Nicosia, Strovolos, Torino, Valladolid, and Vejle) indicated that they need insight in the tools available, an in-depth understanding of these tools and training on how to apply the (selected) tools effectively in their NBS implementation processes. Hence, it is not only important to develop and disseminate tools that can support NBS uptake, but it is also essential to provide potential end-users such as municipal officers with additional support in selecting and applying the right tools for the challenges they are facing.

3.2. Review of Tools That Support Urban NBS Uptake

A large number of tools have been developed that aim to support NBS uptake in the urban environment. Departing from a broader collection of tools, 44 NBS tools have been analyzed as they fulfil the selection criteria set. Figure 1 summarizes the whole list of tools with the main relevant characteristics. The complete tools catalogue, with all tools labeled on the indicators specified in Table 1, can be found in the Supplementary Material S1. While it is an extensive long list of tools, compiled through a structured online search, it should be stressed that the catalogue is not a complete overview of existing tools. Potentially valuable tools can be missing in the catalogue and certain types of tools can be underrepresented as a result of the adopted search and selection criteria and the researchers' language proficiency, comprising English, Spanish, Italian and Dutch. Nonetheless, a complete overview of existing tools does not exist and the presented overview seems to be the most exhaustive overview available at this moment.

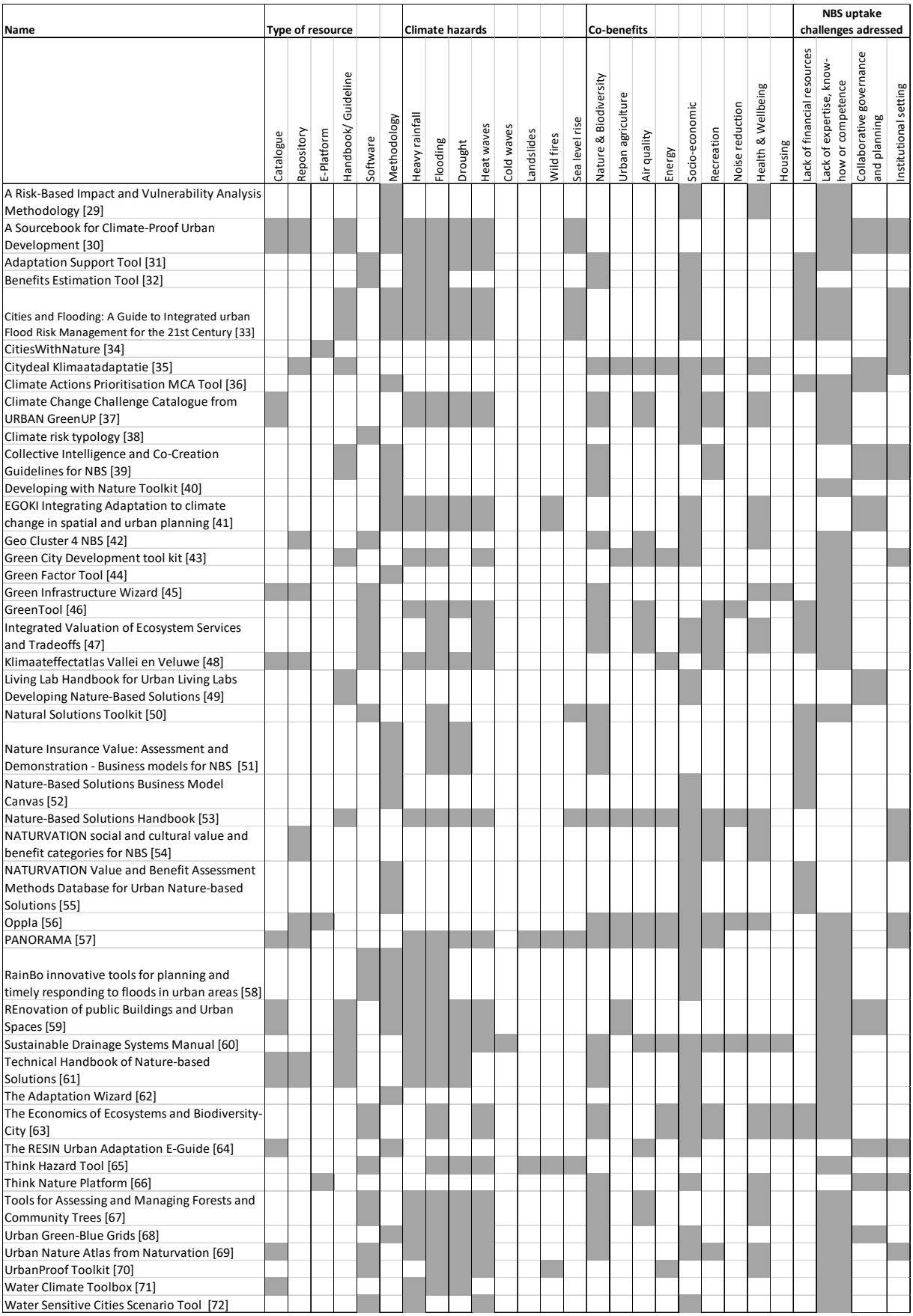

Figure 1. Overview of the reviewed tools and their main characteristics (type of resource, climate hazards and co-benefits addressed and NBS uptake challenges addressed) [29–72].

Firstly, we found that the reviewed tools are rather comparable in terms of their accessibility. Forty-one of the reviewed tools (93%) are free to use and open source. Most of these tools have been developed with national grants or EU research funded projects (e.g., FP7, Horizon2020, Environment and climate action—LIFE, European Regional Development Fund—ERDF, etc.). Nine of these tools request registration to use or download the tool. In addition, we identified three tools developed by private organizations, agencies, research centers or consultancy firms that offer their tools commercially, either through a paid service such as tailor-made trainings (one tool), or by a basic and free version of the tool with a premium option that requires an extra fee (two tools). Thirty-eight of the tools (86%) are provided in English, of which seven are also in one or two other languages such as Dutch, Italian, Spanish or another language. Of the remaining six tools, four are in Dutch and two in Italian.

The 44 NBS tools that were identified consist of different types of resources, including software, methodologies, e-platforms, repositories, handbooks or guidelines and catalogues. Almost three-quarters of the tools (73%) provide qualitative data. Handbooks/guidelines are the only resource that exclusively provide qualitative data, as is the case for the majority of repositories and catalogues. Yet, whereas handbooks generally do not have an analytical purpose, repositories and catalogues have (Figure 1). Thirty-six percent of the tools provide spatial data and 55% of the tools provide quantitative data, entailing primarily software and methodologies. Whereas both methodologies and software mostly have a planning and design purpose, software generally has a more analytical and less inspirational purpose than methodologies (Figure 2). Overall, the majority of tools aim to support planning and design (75%) and/or are informative in nature (70%) Additionally, half of the tools have an analytical purpose and 32% are inspirational. We found that almost all tools can support the research process and awareness creation in the exploration phase (95%) as well as in the preparation phase for NBS planning and design processes (93%). On the other hand, 41% of the tools can be used in the implementation phase to guide NBS installation, initial and full implementation, and only a quarter of the tools can be used in the sustainment phase, to assist monitoring and evaluation processes.

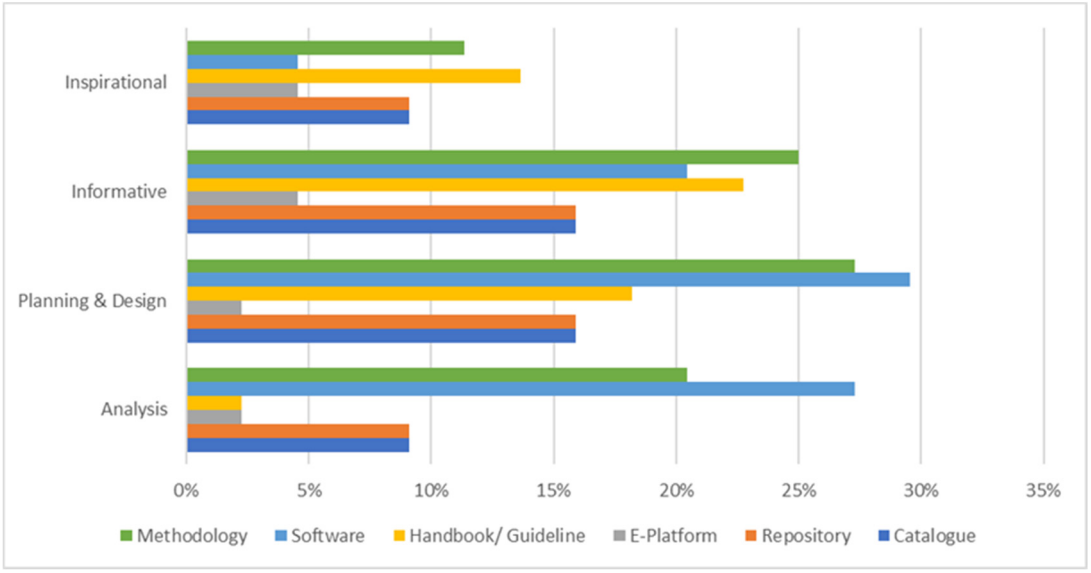

Figure 2. The diverse purpose (inspirational, informative, planning and design and analysis) of the various types of tools per category (methodology, software, handbook, e-platform, repository, catalogue).

All the tools aim to support NBS uptake for urban climate adaptation, but they differ in their specific scope. We found that if the NBS tools focus on specific climate hazards rather than addressing urban climate adaptation more generally, they always focus on more than one hazard. Moreover, tools have been designed primarily with an emphasis on

flooding, heavy rainfall, heat waves, and droughts (Figure 3). Likewise, we observed that all tools address several co-benefits, with most attention for socio-economic benefits (66% of the tools) and nature and biodiversity (50%) (Figure 4).

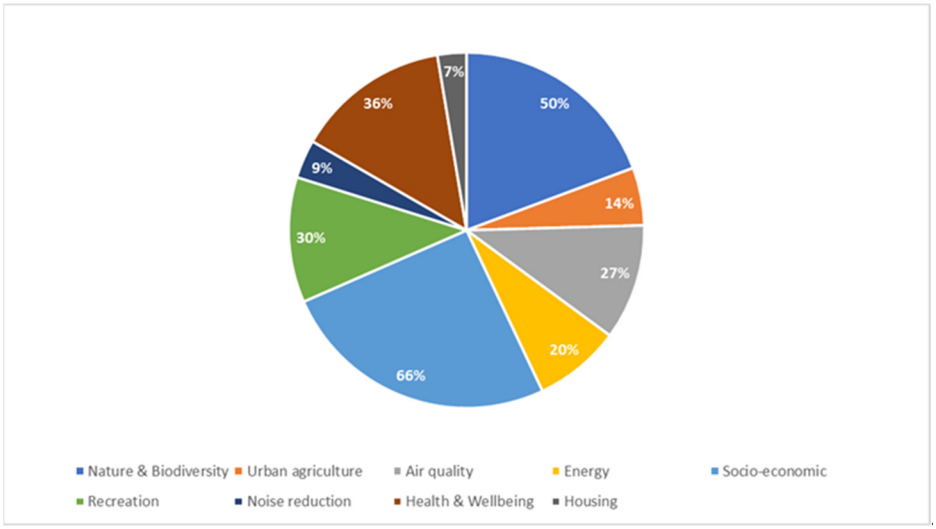

Figure 3. Climate hazards addressed by the tools (%).

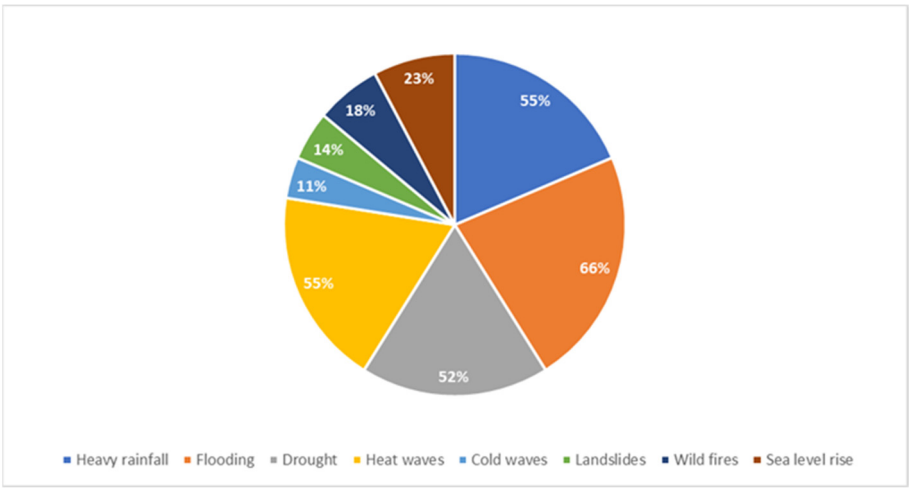

Figure 4. Co-benefits addressed by the tools.

As tools frequently address socio-economic benefits, fifteen and fourteen tools provide economic and social information, respectively. On the other hand, environmental information is provided by 80% of the tools, fifteen tools provide spatial information, and climate information is provided by twenty-three tools. Especially software-type tools provide a specific type of information, 53% of the resources that provide spatial information is software, and so is 48% of the tools that provide climate information. In line with the type of information provided by the different tools, we found that tools can primarily assist in spatial planning (84%) and environmental planning (75%). We found that a relatively smaller share of the tools (61%) can support governance planning, such as community participation, decision making, communication and dissemination of NBS projects with different stakeholders. Thirty percent of the tools can assist with financial planning, by calculating the costs and benefits of NBSs, or explaining how to create sustainable business models for municipalities, the private sector and communities of innovation.

3.3. Synthesis of End-User Needs and Collected Tools

Finally, we assessed the different tools on their ability to support overcoming the specific uptake challenges that cities are struggling with (Section 3.1). Figure 5 shows the number of tools that address the different NBS uptake challenges and the percentage of tools for each NBS uptake challenge that meet a certain tool characteristic. It should be noted that these tools were assessed on their potential to support cities in overcoming these challenges, based on their characteristics, but they were not evaluated on their effectiveness in providing such support. As shown in Figure 5, most of the tools have potential to support overcoming a lack of expertise (31). The other challenges are addressed less frequently: challenges with the institutional setting (13), availability of financial resources (11), and collaborative governance and planning (10). All tools address at least one of the challenges for NBS uptake that are experienced by cities.

		Type of resource						Planning perspective				Type of information					Type of data			Phase of use				Purpose			
Challenge	**Total number of tools**	Catalogue	Repository	E-Platform	Handbook/ Guideline	Software	Methodology	Spatial planning	Financial planning	Environmental planning	Governance	Spatial info	Economic info	Social info	Environmental info	Climate info	Qualitative	Quantitative	Spatial	Exploration phase	Preparation phase	Implementation phase	Sustainment phase	Analytical	Planning & Design	Informative	Inspirational
Expertise, know-how or competence	31	9	7	1	6	15	10	29	8	26	17	15	10	6	28	19	21	19	15	29	29	14	9	17	26	21	9
Institutional setting	13	4	5	3	6	1	4	11	4	11	12	2	3	7	9	6	12	2	2	13	11	3	3	4	9	12	7
Financial resources	11	0	0	0	1	6	5	7	8	9	6	5	11	5	10	4	6	9	4	10	11	4	3	8	8	6	4
Collaborative governance and planning	10	3	2	1	5	0	7	9	2	5	7	1	1	5	6	5	10	2	1	10	9	1	0	1	8	10	6

(**a**)

		Type of resource						Planning perspective				Type of information					Type of data			Phase of use				Purpose			
Challenge	**Total number of tools**	Catalogue	Repository	E-Platform	Handbook/ Guideline	Software	Methodology	Spatial planning	Financial planning	Environmental planning	Governance	Spatial info	Economic info	Social info	Environmental info	Climate info	Qualitative	Quantitative	Spatial	Exploration phase	Preparation phase	Implementation phase	Sustainment phase	Analytical	Planning & Design	Informative	Inspirational
Expertise, know-how or competence	31	29	23	3	19	48	32	94	26	84	55	48	32	19	90	61	68	61	48	94	94	45	29	55	84	68	29
Institutional setting	13	31	38	23	46	8	31	85	31	85	92	15	23	54	69	46	92	15	15	100	85	23	23	31	69	92	54
Financial resources	11	0	0	0	9	55	45	64	73	82	55	45	100	45	91	36	55	82	36	91	100	36	27	73	73	55	36
Collaborative governance and planning	10	30	20	10	50	0	70	90	20	50	70	10	10	50	60	50	100	20	10	100	90	10	0	10	80	100	60

(**b**)

Figure 5. Number of tools that address the four NBS uptake challenges identified (**a**) and the percentage of tools for each NBS uptake challenge that meet a certain tool characteristic (**b**). Colors vary from red (no or few tools) to green (several to most of the tools) having the specific characteristics.

The challenge of the level of expertise, know-how or competence is addressed mostly by resources that are qualified as software (48%), methodologies (32%) and catalogues (29%) (Figure 4). The majority of these tools can be used for spatial (94%) and environmental planning (84%). Related software and methodologies comprise, amongst others, analytical (mapping) tools focusing on risk analysis and environmental impact assessment (e.g., Climate Risk Typology, IVAVIA, and Think Hazard Tool) and decision support tools such as the Adaptation Support Tool (AST), GreenTool, Water Sensitive Cities Scenario Tool that provide planning and design support and guidance. Cities that are in need of information on measures in general, on NBSs for particular environmental challenges, or that would like to know more about experiences with implementing NBSs in practice (3.1.3), could be supported by the identified catalogues, repositories and handbooks. When it comes to the need for information on the effectiveness of measures, it is relevant to note

that the tools mostly provide environmental information (90%) and a large share provides quantitative (61%) and/or spatial (48%) data. Finally, it stands out that a substantial number of tools addressing the level of expertise, know-how or competence can be used in the implementation phase (45%), whilst only 29% of these tools can be used in the monitoring phase. Yet, tools that provide monitoring guidance could be particularly relevant for providing support to overcome this particular challenge, as monitoring implemented NBSs is instrumental for obtaining insights on generated NBS benefits and co-benefits. In comparison to tools addressing the other challenges, only a small share of the tools (29%) have an inspirational purpose.

When the institutional setting is experienced as a challenge, handbooks (46%) and repositories (38%), are the main types of resources that have potential to be supportive (Figure 4). Most tools addressing this challenge provide qualitative data (92%), while only 15% of the tools provide quantitative or spatial data. These tools typically outline key considerations when mainstreaming NBSs for climate-proof urban development and/or share examples of best practices. The Nature-Based Solutions Handbook, for example, provides information to understand the main concepts and facts about NBSs and recommendations for enhanced NBS uptake. The Urban Nature Atlas from Naturvation is a comprehensive database of successful NBS applications in 100 European cities. Additionally, community platforms such as CitiesWithNature and Think Nature Platform were found to be potentially relevant to address this challenge, as they facilitate knowledge sharing and enable collaboration between cities. The tools that can address challenges related to the institutional setting can all be used in the exploration phase (100%) and most are also useful for the preparation phase (90%). These tools mainly have an informative purpose (92%) and/or a planning and design purpose (69%).

Software and methodologies are the main type of resources that have potential to be of use when the availability of (financial) resources is experienced as a challenge. These comprise methodologies for financial planning and software that provide economic (100%) and environmental information (91%) on the costs and/or benefits of NBSs (Figure 4). An example of a tool that addresses the cost of NBSs is the Adaptation Support Tool (AST) that estimates the cost of the implementation and maintenance of NBSs based on unit prices. A methodology that supports the financing of NBSs through business case development is the NBS Business Model Canvas, by enabling the inclusion of long-term benefits in the business case scope. The tools that assist in overcoming a lack of financial resources are all expected to be used in the preparation phase, and all but one in the exploration phase. It stands out that, in comparison to tools addressing the other challenges, a large percentage of the tools addressing the availability of financial resources provides quantitative data (82%) and the majority (73%) is analytical in nature.

The tools that address the challenge of collaborative governance and planning are mostly qualified as being methodologies (70%) or guidelines (50%) (Figure 4). These tools comprise of methodologies for capacity building and stakeholder engagement, as well as guidelines and methodologies for co-creation, living labs and multi-stakeholder processes. An example of the latter is the Collective Intelligence and Co-Creation Guidelines for NBS, which aims to demonstrate and encourage co-creation as a strategy to create aesthetically appealing and socially acceptable NBS designs. Additionally, the multi-stakeholder Think Nature Platform could support in overcoming this challenge as it aims to foster collaboration. Whereas one tool can be used in the implementation phase, all others are to be used in the exploration (100%) or the preparation phase (90%). The RESIN Urban Adaptation E-Guide, which can be used in support of stakeholder analysis, is exceptional for being the only analytical tool that can be used to address the challenge of collaborative governance and planning.

4. Conclusions and Recommendations

This research highlighted challenges municipal officers experience with NBS uptake in urban environments and their demand for tools to overcome those challenges. Our research

revealed four key challenges that municipal officers experience with NBS uptake: level of expertise, know-how or competence; the institutional setting; availability of resources; and the collaborative governance and multi-stakeholder planning approach. Moreover, interviewees and workshop participants expressed that finding and navigating all available tools and resources is challenging and language can be a barrier to using and selecting appropriate tools. The performed review reveals that many tools for NBSs already exist. Departing from an analysis of more than 70 tools, the authors identified 44 online tools to support the uptake of urban NBS for climate adaptation. These tools reviewed have been collected in a catalogue of NBS tools that provides municipalities, decision-makers, urban professionals, researchers and other actors with enhanced access to potentially valuable NBS tools to enable sound decision making for NBS planning and implementation.

The catalogue of tools provides researchers and tool developers with insights into potential market saturation as well as the scarcity of certain types of tools that may be a potential niche for new tool development. It should be questioned whether developing a new tool is always the best option, or whether the modification of an existing tool would be more (cost) effective. For example, only a few of the tools are available in multiple languages and translating tools could make them accessible for a larger group of end-users. A potential niche could be tools that focus on climate hazards other than flooding, heavy rainfall, heat waves and droughts, and those that address a multitude of benefits of NBS. Our review revealed that advanced tools with a focus on sea level rise, wildfires, landslides and cold waves are still scarce and so are those including co-benefits other than biodiversity and socio-economic development. Another gap that we see are tools for innovative NBS business models and financing mechanisms (see, e.g., [68,69]), tools that provide dedicated training for capacity building and aim at human and financial resources to NBS implementation. These are essential strategies towards more structural and strategic incorporation of NBS in urban planning and towards aligning siloed (municipal) lines of working, departmental agendas and timeframes that are hampering the uptake of NBS [16,20,28]. Moreover, existing tools are predominantly tailored to addressing a lack of expertise, know-how or competence, with 70% of tools addressing this challenge, whilst tools that can assist financial planning and those supporting integrated and collaborate approaches to urban planning and governance are underrepresented. Hence, we also see key opportunities in researching and implementing new governance, planning and business models that are based on more integrated and collaborative approaches, and to translate the findings and lessons into practical and replicable tools.

Finally, we argue that developing tools in itself is not enough for the mainstreaming and uptake of NBSs. Several of the reviewed tools have been developed as part of (EU) funded research projects that do not provide support and maintenance after the project has finished, which is often a requirement for tools to be used by end-users. Although cities have been involved in these projects as potential end-users, many of these tools were developed as a technology push and not necessarily to fulfil the needs of the end-users. We argue that departing from users' and cities' needs and challenges should be at the basis of innovative tool development for NBSs. Hence, it deserves further research to evaluate which tools' characteristics are crucial for effectively providing end-users with the support they need, through, e.g., pilot projects or living labs that involve researchers, tool developers, and other end-users. Not only would such processes offer potential to translate cities' challenges into practical and widely applicable tools, without "reinventing the wheel", but at the same time, such processes offer the opportunity to gain experience with NBS implementation. Such "learning by doing" is essential to overcome the barriers and advance in the mainstreaming and uptake of NBS.

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