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Transformation tools enabling the implementation of nature-based solutions for creating a resourceful circular city

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Abstract

The linear pattern of production-consumption-disposal of cities around the world will continue to increase the emission of pollutants and stocks of waste, as well as to impact on the irreversible deterioration of non-renewable stocks of raw materials. A transition towards a circular pattern proposed by the concept of 'Circular Cities' is gaining momentum. As part of this urban transition, the emergent use of Nature-based Solutions (NBS) intends to shift public opinion and utilize technology to mitigate the urban environmental impact. In this paper, an analysis of the current research and practical investments for implementing NBS under the umbrella of Circular Cities is conducted. A combined appraisal of the latest literature and a survey of ongoing and completed National-European research and development projects provides an overview of the current enabling tools, methodologies, and initiatives for public engagement. It also identifies and describes the links between facilitators and barriers with respect to existing policies and regulations, public awareness and engagement, and scientific and technological instruments. The paper concludes introducing the most promising methods, physical and digital technologies that may lead the way to Sustainable Circular Cities. The results of this research provide useful insight for citizens, scientists, practitioners, investors, policy makers, and strategists to channel efforts on switching from a linear to a circular thinking for the future of cities.

Key words: assessment methods, Circular Cities, Nature-based Solutions, policies and regulations, stakeholders' awareness and engagement

ABBREVIATIONS

NBS	Nature-based Solutions
CE	Circular Economy
GI	Green Infrastructure
ICT	Information and Communication Technology
DSS	Decision Support Systems
KESI	Key Environmental and Socio-Economic Indicators
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
MFA	Material Flow Analysis
CBA	Cost Benefit Analysis
PD	Participatory Design
UM	Urban Metabolism
HHA	Harvest to Harvest Approach
SS	Self-Sufficiency
MAES	Mapping and Assessment of Ecosystems and their Services
S-LCA	Social Life Cycle Assessment
ES	Ecosystem Services
IO	Input-Output
NW	Networking
RIA	Research and Innovation Action
IA	Innovation Action
CSA	Coordination and Support Action
FET	Future and Emerging Technologies
II	Implementation and Integration
TRLs	Technology Readiness Levels
WG	Working Group

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SDGs Sustainable Development Goals
R&I Research and Innovation

INTRODUCTION

Cities are complex systems under continuous evolution, whose internal dynamics and process interactions generate impacts on the population's health, socio-economic well-being, and the environment (Alberti 2008; Pickett *et al.* 2008). Nowadays these impacts are mainly driven by a 'linear' behaviour according to which exploitable resources are transported to the cities to provide the necessities of urban consumption and waste dynamics. The patterns of acquisition, consumption and the subsequent waste disposal of resources pose environmental and socio-economic implications. These patterns may also cause irreversible deteriorations of non-renewable stocks of raw materials and huge waste discharged in the outflow of the urban system (Brunner & Rechberger 2016). The concept of 'circularity' is, therefore, gaining popularity among urban planners and decision makers (Petit-Boix & Leipold 2018; Prendeville *et al.* 2018; Williams 2019; Zeller *et al.* 2019) to counter the imbalances caused by unsustainable linear practices. The effect of consuming diminishing raw materials at a faster rate than the ability of nature to restore is a matter of serious global concern.

Concurrently, the emergent concept of Nature-based Solutions (NBS) promotes the circular use of resources making use of closed nutrient, water, and energy cycles by reusing waste rather than discarding it (EC 2015a). In urban areas, NBS could reinforce economic growth, which is highly dependent on the quantity and quality of natural resources, as well as on their availability (González-Val & Pueyo 2019), by promoting the sustainable use of natural resources and by harnessing natural processes (Connor 2015). The enhanced natural capital, as well as the efficient use of resources (i.e. energy and materials), facilitated by working with nature, would further build on the circular economy (CE) (UN 2018). Since CE initiatives at urban scale aim at transforming cities into sustainable and circular systems (Petit-Boix & Leipold 2018), NBS following the concept of CE as an intermediate link, can be seen as enablers to the transition from linear to Circular Cities. In this paper, we refer to NBS as defined in Langergraber *et al.* (2020).

Traditionally, cities have been shaped by institutions (local, regional or national) to comply with regulations, while fostering socio-economic development. Current urban policies, legislation and regulations are generally written in and for a linear economy thus, they may (unintentionally) hinder the transition to a CE. According to Stewart *et al.* (2016), policies and regulations can hamper CE by providing: (i) unclear or fuzzy messages, (ii) a complex system of changing regulations (e.g. multiple sectoral and interacting regulations on water, energy, waste, environment impact assessment), (iii) low pressure and a lack of control, and (iv) a limited space for innovation. Additionally, NBS are still poorly addressed by current policies and regulations related to CE. This may be due to the fact that NBS is a relatively novel concept in dealing with the challenges faced by society (i.e. societal challenges), and therefore, still searching for its place under different policies and regulations. NBS aims to address challenges associated with climate resilience, health and well-being in urban areas (IUCN 2012; Cohen-Schacham *et al.* 2016), integrating established ecosystem-based approaches, such as biodiversity, ecosystem services (ES), green infrastructure (GI) etc., and aiming in broadening them, in order to holistically tackle issues of environmental, economic and social nature in building resilience (Raymond *et al.* 2017a, 2017b). Within European Research and Innovation (R&I) programmes, e.g. 'Horizon 2020', NBS extend the aforementioned approaches involving biodiversity and ecosystem services aligned with goals of innovation for growth and job creation and work towards sustainable societal development (Maes & Jacobs 2017; Nesshöver *et al.* 2017). Therefore, due to NBS systemic nature there are inherent difficulties in integrating such a complex concept in policies and regulations (Niță *et al.* 2017). Unsurprisingly,

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supporting frameworks for NBS are provided by other instruments, such as the EU green infrastructure strategy and the biodiversity strategy.

However, policies and legal frameworks can also accelerate the transition towards Circular Cities supporting solutions, such as NBS. Such an approach appears at the EU level since the Paris agreement with a set of EU strategies and policy papers connecting sectoral regulations and initiating a revision of existing Directives when further coherency is necessary. Thus, the EU Circular Economy package, launched in 2015 with an action plan composed of 54 items, is presented as a tool to foster the transition and encompass most of the barriers. Two key instruments are foreseen by the EC report on the implementation of the Circular Economy Action Plan (COM 2019). (i) Investments in innovation and in adapting the industrial base; with R&I (H2020), Environment (LIFE) programmes, Cohesion Policy or financing facilities. To overcome the regulation limits, pilot innovation deals have been introduced in 2016 and should be extended. (ii) Strong stakeholder engagement to ensure co-design and social acceptance of solutions.

In this regard, stakeholders play a central role in supporting the transition from linear to circular pathways in cities. The long-term viability and durability, the extent of scalability for the adoption and implementation of actions, projects, and/or solutions, as well as the diffusion of good practices are perceived as key in achieving and maintaining this transition (Kabisch *et al.* 2016). The involvement and collaboration of public, private and civil actors in the governance of NBS – enabling Circular Cities – can reduce barriers to NBS adoption on a wider scale of application (Frantzeskaki *et al.* 2014; Kabisch *et al.* 2016). The partnering of different actors can moreover improve the circulation of knowledge regarding NBS and Circular Cities (Ugolini *et al.* 2015). Citizens' participation and involvement can further facilitate the communication of information on NBS and their diffusion by the community (Kabisch *et al.* 2016). In this context, the use of participatory evaluation can be seen as a way to respect the legitimacy of different views on NBS quality, as well as to apply multiple perspectives provided by the different stakeholders (Nesshöver *et al.* 2017).

Another issue related to the relatively new concepts of NBS and Circular Cities is identified in the persisting challenges of the costs and benefits of circularity methods in cities (Raymond *et al.* 2017a, 2017b). Although the costs of the shift are tangible and measurable, the burden of proof on the short-term benefits of NBS is still on the proponents. Assuming that the long-term (e.g. resilience and well-being) impact is understandable by stakeholders, the intangible short-term benefits are more difficult to convey. It seems that one of the major shortcomings is the lack of holistic and widely accepted methodology and/or framework to assess the circularity potential of such systems into the bargain, as argued by (Kabisch *et al.* 2016). There is a need for reaching consensus on the individual instruments and tools (methods, indicators, models, databases, etc.) capable of comparing linearity against circularity. The aim is to offer a roadmap and the tools to converge methodologies and integrated functionalities to estimate the costs and benefits of circular against existing linear solutions. The roadmap paves the way and the tools to provide the means to achieve the goal. The proposed toolbox would contain methods and models to quantify a set of Key Environmental and Socio-Economic Indicators (KESI) integrated by Information and Communication Technology (ICT) and in the form of software applications to aid in decision making (i.e. Decision Support Systems). These platforms will become the instruments to compare circular against linear scenarios, and demonstrate short-term and long-term tangible and intangible benefits of modern Circular Cities. Such objective measurements will become the drivers of public awareness/education and investment.

The goal of this review paper – developed within the framework of the COST Action Circular City (CA17133 2018) – is threefold: (i) to identify and group specific tools and methods that are used to assess NBS for implementing and improving circularity in cities, (ii) to identify means of society and stakeholders' engagement and awareness, and (iii) to identify barriers and facilitators within current policies and regulations in order to promote and enable the implementation of NBS for improving future city transitions. The identification of current gaps, needs and opportunities will help to transfer research results into the market and to upscale existing pilot applications into the ground of concrete decision making for NBS.

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METHODOLOGY

To identify the current gaps and opportunities regarding the transformation tools enabling the implementation of NBS for creating Circular Cities as stated in the introduction, an analysis was performed that includes: (i) the interconnections between policies and regulations, engagement and participation of stakeholders, and tools and assessment methodologies, during the implementation of NBS (see section The Scope of Nature-based Solutions in Circular Cities); (ii) a literature review focusing on the up-to-date scientific research (see section Overview); and (iii) a survey of projects related to NBS for creating Circular Cities that would enable the comparison between scientific research and practical applications (see section Survey Results and Discussion). The paper focuses on the survey of National-European research and development projects, which sets a delimitation of this study with regards to NBS contributions to sustainable research and development in European context.

Literature review approach

The conducted literature review (see section Overview) is divided into three sub-sections, namely Policy and Regulations, Stakeholder Engagement and Awareness, and Tools and Methods. The review is based on peer-reviewed papers published in international scientific journals and on high-level policy documents. The identification of the relevant papers was conducted using related key words in the Science Direct and Scopus databases. High-level policy documents were chosen as the planning and implementation of NBS is supported by such documents.

The focus of the review is to: (i) identify current policies and regulations at EU level that should be conserved when implementing NBS for Circular Cities, as well as to understand the importance of the social, economic and environmental dimensions to be considered in and inform the policies (see section Policy and Regulations); (ii) identify the challenges related to public awareness and social acceptance, as well as to review methods that have been developed to increase the stakeholders engagement in NBS (see section Stakeholder Engagement and Awareness); and (iii) identify promising tools and methods that have been developed by researchers and can be used to assess the different dimensions (environmental, economic, and social) of the effectiveness of NBS (see section Tools and Methods).

Project survey approach

The members of this COST Action hold key knowledge on different aspects of NBS and Circular Cities and they participate in national, European and academic projects related to these subjects. Therefore, past and ongoing projects were reviewed and a meta-analysis of policies and regulations, stakeholders' awareness and participation, as well as the tools and methods assessing the technologies and systems was conducted.

Data from the projects were collected through a specially designed online questionnaire, which was carried out during March 2019. The main aim of the survey was to collect useful information on the different projects in order to compare and identify the gaps between scientific literature and practical applications.

The questions included in the questionnaire were divided in four main categories. The first category included questions related to general information of the projects, such as:

- Project title;
- Project type – the projects are divided by: (i) Networking (NW), (ii) Research and Innovation Action (RIA) and Innovation Action (IA), (iii) Coordination and Support Action (CSA), (iv) Future and Emerging Technologies (FET), and (v) Implementation and Integration (II);
- Project stage – from recently started to completed;

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- NBS focus – four categories, corresponding to the working groups (WG) of this COST Action, were specified: Built Environment (WG1), Urban Water (WG2), Resource Recovery (WG3), and Urban Farming (WG4);
- Implementation level – i.e. conceptual, experimental, on-ground, and capitalization projects;
- Application scale – *micro* (technology, material, energy, etc.), *meso* (building, neighbourhood, landscape, etc.), and *macro* (district, city, region, etc.);
- TRL of the different technologies – the scale ranges from 1 to 9 with TRL 1: basic principles observed and reported, and TRL 9: system ready for full-scale deployment;
- SRL of the project – the scale ranges from 1 to 9 with SRL 1: identifying problem and identifying societal readiness, and SRL 9: actual project solution(s) proven in relevant environment.

The second category was related to the methods that were used for the assessment of the NBS and the ICT tools that were either developed or used in the projects. The third category was focused on the type of policies and regulations that were considered in the project, the main barriers that were identified in the projects, as well as supporting measures (of policy or regulations) to ensure the success of the project. Finally, the fourth category was related to the type of the stakeholders involved in the project, the barriers for the implementation of project activities related to stakeholder awareness and engagement, the types of public participation tools and techniques used in the project and the level of stakeholders' engagement in the project.

A total number of 47 relevant research projects were studied (the list of the reviewed projects can be found in Appendix 1) and the results of the conducted survey are presented under Survey Results and Discussion.

THE SCOPE OF NATURE-BASED SOLUTIONS IN CIRCULAR CITIES

There are four main steps for the implementation of NBS in creating Circular Cities: (i) planning, (ii) design, (iii) assessment and, (iv) communication of results. As illustrated in Figure 1, it is important to close the circular process starting a new plan based on the information provided in the communication of previous implementations. Tools are used in all of the four steps in order to enhance the dialogue among the different actors, as well as the engagement and participation of the stakeholders to induce sustainable changes and assess the environmental, economic, and social improvement of the cities, and finally to inform the policy making.

The **planning** phase requires information about the regulations that must be fulfilled and the city where the NBS will be implemented aiming at becoming a circular city (specific problems to be solved, citizens' awareness and perception about the problem, characteristics of the city including potential sites to implement the NBS, possible/alternative NBS to implement, and similar case studies and demo sites implemented around the world). The typical tools used for planning include Decision Support Systems, Multi-Criteria Decision Analysis, repositories of case studies (literature or

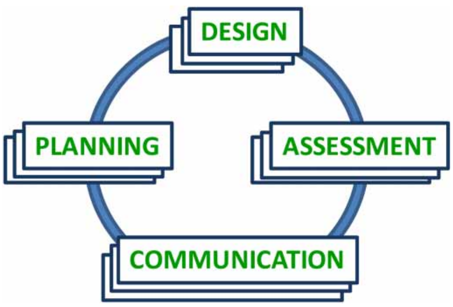

Figure 1 | Circular process for the implementation of NBS in Circular Cities.

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web-based), models and databases with information about the former value of the indicators that will be used for the assessment, exploratory/visualization tools to determine the characteristics of the city/sites (e.g. aerial images, land space, green coverage, etc.), and participatory digital platforms. Most of these tools were applied in literature case studies, but they still have to overcome some serious challenges before reaching the market and being fully applied for decision makers (McIntosh *et al.* 2011; Poch *et al.* 2017).

The **design** and implementation requires the use of engineering design knowledge, process models and specific software. Involving general stakeholders and the specific neighbourhood citizens to co-design the NBS becomes crucial for the acceptance and engagement of the society.

The **assessment** phase includes process performance monitoring (sensors, instrumentation, automation, control) and any measurement or assessment of the impacts (beneficial or detrimental) of the implemented NBS (by using methodologies, such as Life Cycle Assessment – LCA, Life Cycle Costing – LCC, Cost Benefit Analysis – CBA, etc.). Moreover, specific software, web-based questionnaires and apps (e.g. citizen science, where the citizens become the 'sensors' for monitoring both the performance and the impact of the NBS) are usually used for this purpose.

Finally, the **communication** phase includes the dissemination to citizens and stakeholders (for their real engagement and in order to increase social perception about the new services of the Circular Cities) and any potential exploitation activities. Efficient communication should make the planning a living process, while revised planning based on communication starts the whole implementation cycle again. The most typical tools for communication are social media and web-based platforms that include repository databases, case studies, user-friendly Decision Support Systems (DSS), simulations, and participatory platforms. This step is the key to providing information to new cities that want to become resourceful and circular. Excellent science needs effective communication and dissemination. Bringing research and its outcomes to the attention of non-scientific audiences, scientific peers, potential business partners or policy makers fosters collaboration and innovation. Strategic communication and dissemination will help to explain the wider societal relevance of science, build support for future research and innovation funding, ensure uptake of results within the scientific community, and open up potential business opportunities for novel products or services.

OVERVIEW

Policy and regulations

Regulation and governance arrangements can be considered as tools supporting policy strategies. Figure 2 presents the different facets of these three pillars, i.e. policy, regulation and governance, which are necessary for the long-term stability of NBS for circular city initiatives.

The governance of NBS emerges as a complex phenomenon, involving multiple social and political actors, premises and visions. Defining the appropriate mix between the involvement of state, local authorities, private sector and grassroots movements remains challenging, in particular in terms of cost sharing and long-term sustainability. Participatory approaches with multiple stakeholders' impacts evaluation and a strong civil society engagement appears as a successful approach governance (Naturvation 2017).

In the context of this paper, a state-of-the-art analysis of EU regulations and policies is conducted. An inventory of a wide range of EU instruments to be conserved when implementing NBS for Circular Cities is presented in Table 1. The different EU regulations are categorized based on their content and they are linked relevantly to the four different challenges addressed by NBS, as presented in (Langergraber *et al.* 2020). Due to its wide diversity, the local dimension requires further research, in particular considering the relationships between Circular Cities and their surrounding

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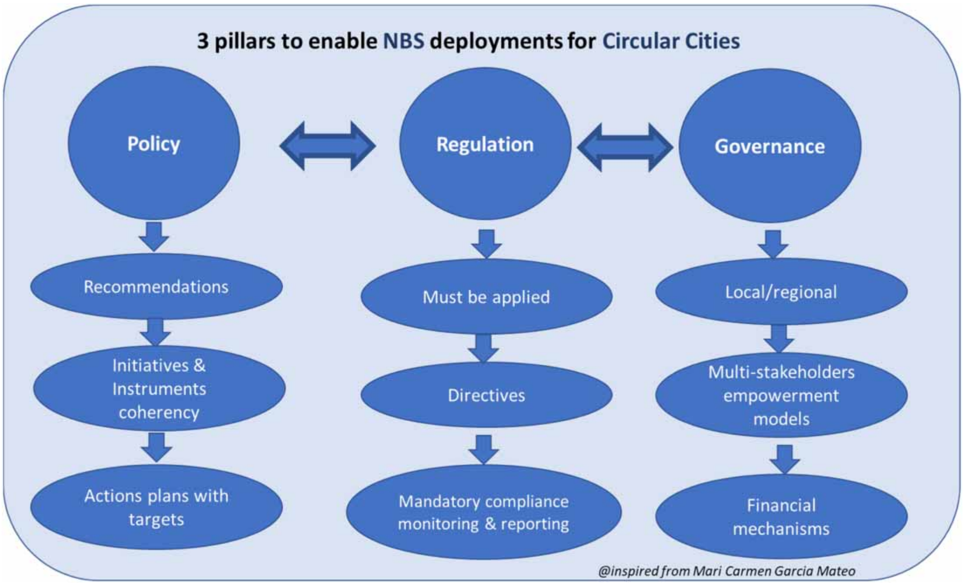

Figure 2 | Three pillars to enable NBS deployments for Circular Cities.

Table 1 | EU policies and regulations for the implementation of NBS in Circular Cities

EU policies / strategies	EU regulations	
• Circular Economy Package: Action Plan and Monitoring Framework • Green Infrastructure Strategy • Bio-economy strategy • Regional Development and Cohesion Policy • Biodiversity strategy • Common Agricultural Policy (CAP) • Framework Programme for Research and Innovation • Environment Action Programmes	Resource recovery	Waste Framework Directive (2008/98/EC)
	Built environment	Energy performance of buildings Directive (2010/31/EU) Energy efficiency Directive (2012/27/EU)
	Built environment Water Resource recovery Urban farming	Environmental Impact Assessment (EIA)
	Resource recovery Urban farming	Sewage Sludge Directive (86/278/EEC)
	Resource recovery Urban farming	Fertilisers Regulation (EC) No. 2003/2003
	Water Resource recovery Urban farming	Water Framework Directive (2000/60/EC) Groundwater Directive (2006/118/EC) Drinking Water Directive (98/83/EC), revised on 1 Feb 2018 Urban Waste Water Directive (91/271/EEC) Minimum requirements for water reuse COM (2018) 337 (2018/0169 (COD))

environment, such as the river basin when considering aquatic ecosystems or the whole region for secondary products created from urban circular economy (e.g. fertilizers derived from sludge or organic waste).

Regulations are often seen as barriers for innovation, but they are also providing an enabling environment for new product development and marketing.

UN and ISO non-binding frameworks support NBS implementation for Circular Cities. For example, the frameworks on 'treated wastewater for irrigation', 'drinking water quality guidelines' and 'Sustainable Development Goals' (SDGs) are worth mentioning. Often it is challenging translating such strategic and visionary frameworks at the operational level and in local contexts, especially in areas with weak planning and regulation systems (i.e. some areas in Central and Eastern Europe). Moreover, even the EU Directives contain many non-legally binding articles related to water reuse.

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For example, Article 12 of the UWWD suggests that 'Treated wastewater shall be reused whenever appropriate. Disposal routes shall minimize the adverse effects on the environment'. However, it is the member states that decide if and where it is appropriate. After years of discussion, water reuse standards are being accepted at EU level, but they are only related to reuse in agriculture. Other uses (e.g. in urban areas) remain unregulated at EU level.

The EU regulations listed in Table 1 show that the need to protect natural capital and value ES are recognized as being crucial to progress towards the sustainable development goals. A notable example is represented by the European Union actions towards sustainable growth for Europe 2020 and EU Biodiversity (COM 2011) and Green Infrastructure (COM 2013) strategies. Furthermore, the European Union Thematic Strategy on the Urban Environment (COM 2005) recognizes that it is in urban areas that the environmental, economic and social dimensions of the EU Sustainable Development Strategy come together most strongly (Raymond *et al.* 2017a, 2017b). Therefore, NBS are directly relevant to several policy areas and through their systemic nature they interact with many others (land use, planning etc.).

The EU policies/strategies reported in Table 1 do also suggest that sustainability assessment has recently become an important issue for policy and decision makers in Europe due to a recognized requirement of balance between environmental, economic and social policies. The interlink between these policies requires a simultaneous consideration of the intersection between environment, economy and society of sustainable development to have a better environment, economic growth (ideally decoupled from resources exploitation) and welfare of society without compromising the wealth of future generations as indicated in Brundtland Commission definition of sustainable development (WCED Brundtland Commission 1987). There exists an inherent risk of new technology implementations on the balance of policies related to the three pillars of sustainability.

Although the social dimension to sustainability is widely recognized, performing a social assessment is difficult due to a lack of indicators that can be directly employed in technical analyses. Therefore, attention has been given to determination and quantification of social factors or the interaction of the social variables in a complex relationship. Without quantified and properly determined social factors, the impact of policies and technologies on the well-being of society and environment may not be a solid base for future policy strategies. Thus, the assessments of economic and environmental dimension without considering the social effects are insufficient (Carrera & Mack 2010). The social acceptance of technology, renewable energy and environmental policies are progressively becoming more important for policy and decision makers worldwide aiming to design policies that reach attempted targets smoothly with community support. Therefore, social acceptance could be considered to be a promising factor for social assessment. As an emerging solution to environmental problems, NBS related projects or technologies are subject to social acceptance. There is a need to consider aspects of urban management, governance, biodiversity etc. within a society and integrate diverse systems of knowledge and values for NBS design and implementation in order to be socially comprehensible and acceptable to a range of stakeholders (Maes & Jacobs 2017).

Stakeholder engagement and awareness

Public awareness and social acceptance of the NBS for Circular Cities is important for its proliferation and success in the future. Kabisch *et al.* (2016) identified that one of the major impediments on proliferation of NBS is the traditional structures of city departments and the 'sectoral language', which traps knowledge into 'sectoral silos'; or the so-called compartmentalization of professionals with different educational background and different objectives (Brink *et al.* 2016). Implementation of NBS requires cooperation across departments of the administration or between various actors with different, and sometimes, competing objectives. Therefore, there is an imperative need of an agreement on the societal values, based on which urban development will be planned and adopted.

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In order to be able to communicate and create impact, all stakeholders should refer to universal: (a) definitions of the key concepts, (b) values and valuing system, (c) metrics and indicators, (d) benchmarks and points of reference. Such an approach creates a common language and the foundations of the information and knowledge to be shared and customized for stakeholders (e.g. public, investor, regulator, and policy maker).

Provided the message can be conveyed appropriately, the next challenge is to assess the willingness of stakeholders to accept and adopt the solutions offered to them. In other words, what kind of short- and long-term benefits against the investments are made. This is especially relevant when the former is relatively immediate and the latter takes longer to implement.

Wüstenhagen *et al.* (2007) suggest three elements of social acceptance: socio-political, community and market acceptance. Note that, the convergence of socio-political, community and economic factors determines the '*willingness to accept*'. Socio-political acceptance can be enabled through regulatory frameworks and government standards (Beck & Martinot 2004).The benchmarks and measurable indicators of socio-political factors should provide the framework for firstly examining the procedural justice, which refers to decision making with respect to the collective interests of all stakeholders (Walker 2009). The second indicator of socio-political factors of acceptance is the distributional justice. Social trust can be achieved by fair distribution of costs and benefits and equal rights of access to information by citizens and decision makers. Efforts are necessary to quantify socio-political acceptance, as this is one of the major components in order to achieve social acceptance (Rosso-Cerón & Kafarov 2015). In the case of NBS, even though a small but growing number of countries have adopted regulatory frameworks promoting them (WWAP 2018), in the majority of cases, a universal and precise legal framework for NBS and following procedures for stakeholder awareness and engagement is still lacking and thus, limiting the outputs of the projects.

Community acceptance stands for local stakeholders' impression of the benefits that new NBS technologies or circularity initiatives bring to their respective communities. Normally, the methods for an objective examination of community acceptance, is the level engagement with disseminated information about projects and technologies (e.g. relevant subscription on social media, specialist magazines, local media, etc.). Furthermore, active and voluntary engagement of the community with surveys, attending town hall meetings, focus groups are other modes of increasing awareness as well as gauging acceptance. Roddis *et al.* (2018), for example, focused on the community acceptance of onshore wind and solar farms implementation plans in Great Britain (for the years between 1990 and 2017) by composing a set of indicators.

Market acceptance mainly gauges consumers' utility towards paying or contributing to an initiative or product. Added to the consumers are the role of investors and the business-to-business relationships (e.g. value chains) and their perception of short- and long-term cost and benefit of resource allocation. Wüstenhagen *et al.* (2007) for example, provide an insight to the attitudes of international companies towards different initiatives.

As the engagement of stakeholders in NBS to realize Circular Cities is widely understood and increasingly highlighted in the literature, some methods that have been developed to increase the stakeholders' engagement have been additionally reviewed. Design thinking is one of them, which deploys the typical design workshop setting for iteratively prototyping ideas and can be inscribed within the umbrella of Participatory Design (PD). PD aims at incorporating end-users as full participants in development processes. Mazé (2007) compares PD to user-centered design, which draws on diverse means of studying, analyzing and incorporating user needs into product development. PD focuses on different means for bringing design processes, representations, and products to participation by stakeholders with diverse skills and expertise. In Scandinavia, Atelier (Binder *et al.* 2011) defines participatory design as an approach that attempts to involve end-users in the design process. The author characterizes DT similarly to Redström (2008) 'use before use'. Atelier's 'design things' is inspired by Schön's reflective practitioner (Schön 1983) following an iterative design process through

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envisioning, prototyping, and experiencing. Through these phases, participants undergo emotional and cognitive experiences and they express themselves by engaging in practical action together, in a group. The inclusion of creativity can take different forms in different participatory approaches used today (Rizzo *et al.* 2015).

According to a recent study on Food Policy Councils (Bassarab *et al.* 2019), the most widespread strategies to raise stakeholder engagement include encouraging community members to participate in actions realizing NBS, hosting public events and forums, surveying community members, distributing newsletters, developing specific community engagement strategies, or cross-promoting partner organizations' events. Time, lack of basic knowledge on NBS and lack of engagement plan are also decisive factors to achieve stakeholders' engagement on a high level.

Tools and methods

According to EC (EC 2015a), NBS can address one or multiple societal challenges in sustainable ways and simultaneously provide multiple co-benefits for health, the economy, society and the environment. Despite such strong belief, one can observe a severe lack of practical and targeted guidance for assessing the impacts of NBS within and across different societal challenges (Raymond *et al.* 2017a, 2017b, 2017c). Previous studies have either: (i) assessed the performance of NBS with regard to specific challenge areas, such as regulating urban surface runoff (Zölch *et al.* 2017); (ii) assessed the performance of NBS with regard to their multiple co-benefits and compared them to alternative solutions, e.g. the study of Liquete *et al.* (2016); (iii) examined a set of indicators that can be used to measure the effectiveness of NBS addressing a specific societal challenge and the co-benefits, e.g. the studies of Kabisch *et al.* (2016) and Xing *et al.* (2017); or (iv) developed conceptual frameworks that still lack operationalization (e.g. Raymond *et al.* 2017a, 2017b; Calliari *et al.* 2019).

The same issue arises for CE initiatives realizing Circular Cities (i.e. lack of practical and targeted guidance for assessing circularity initiatives), as the available published data is insufficient to assess these strategies at the city-scale. On the one hand, most of the cities' initiatives are accessible in the cities' web pages and databases, i.e. grey literature (e.g. Bastein *et al.* 2016; Glasgow Chamber of Commerce 2016; Mairie de Paris 2017; Sack-Nielsen 2018). On the other hand, not all of the previous studies, assessing the environmental performance of CE strategies – published on peer-reviewed journal articles – have framed their assessment within the CE context (Petit-Boix & Leipold 2018).

In this work, a transdisciplinary approach – since circularity and sustainability concepts necessarily depend upon the interaction between the three spheres of society, economy and environment – has been undertaken to identify the tools and methods that have been used to assess NBS enabling circularity transitions from the literature. After the first classification of these tools and methods from the literature, the additional projects' survey – presented under Overview – was used to identify the most common tools and methods that are actually used in projects. Therefore, this large set of instruments, potentially suitable to address many of the open transdisciplinary questions associated with the quantitative characterization of Circular Cities, was summarized into categories (as presented in Table 2).

The analysis of the tools and methods used in the projects indicates that there is an extensive diversity in the use of methods for the assessment of NBS; however, their application is mainly case specific without taking advantage of the complementary features that often those methods offer. This is the case, for example, for the majority of the methods emerging from the present survey, i.e. LCA and ES assessment with MAES. Their screening in the context of the selected projects suggests that more research efforts are needed to identify mutual strengths and integrate different modelling approaches, e.g. the cascade modelling framework (Potschin-Young *et al.* 2018), to address multiple challenges, such as the accounting for bundles of services at different spatial and temporal scales. Some recent literature focusing on the combination of LCA and ES methods, for example, fosters the alignment of existing ES

Table 2 | Description of the most common tools and methods for NBS assessment

Name of Tool/Method	Description from Literature	Scope of Assessment: Environmental	Social	Economic
Life Cycle Assessment (LCA)	'LCA addresses the environmental aspects and potential environmental impacts (e.g. use of resources and the environmental consequences of pollutant releases) throughout a product's life cycle from raw material acquisition through production, use, end-of-life treatment, recycling and final disposal (i.e. cradle-to-grave)' (ISO 14040 2006).	x		
Life Cycle Costing (LCC)	'LCC is a technique that assesses costs over the life cycle of a product or a system' (Rödger *et al.* 2018).			x
Cost Benefit Analysis (CBA)	'CBA compares the gains and losses associated with an investment project (a road, railway line, port, urban expansion, etc.) or with a policy, e.g. the setting of an environmental standard' (Pearce 1998).	x	x	x
Material Flow Analysis (MFA)	'MFA methodology evaluates the flow of materials entering and leaving a system and their impact in the environment' (Rincon *et al.* 2013).	x		x
Urban Metabolism (UM)	'Model that quantifies processes and allows the measurement of four main cycles or flows: Water, materials, energy and nutrients' (Kennedy *et al.* 2007; Pincetl *et al.* 2012).	x		
Harvest to Harvest Approach (HHA)	'Urban Harvesting reduces single source dependence by optimizing the demand and by harvesting local resources' (Wielemaker *et al.* 2018).	x		
Self-sufficiency (SS)	Self-sufficiency is achieved by reusing output as an input, (partially) covering the input demand. SSI can be used as a measure for the extent of self-sufficiency of a system (Wielemaker *et al.* 2018).	x		
Mapping and Assessment of Ecosystems and their Services (MAES)	'MAES is a conceptual framework that links socio-economic systems with ecosystems via the flow of ecosystem services and through the drivers of change that affect ecosystems either as consequence of using the services or as indirect impacts due to human activities in general' (Maes *et al.* 2013).	x	x	x
Social Life Cycle Assessment (S-LCA)	'A social and socio-economic Life Cycle Assessment (S-LCA) is a social impact (and potential impact) assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle encompassing extraction and processing of raw materials; manufacturing; distribution; use; re-use; maintenance; recycling; and final disposal' (Andrews *et al.* 2009).		x	

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classification systems to accepted life cycle inventories (LCIs), and the implementation of a consensual ES-LCA framework (Othoniel *et al.* 2016; Verones *et al.* 2017; Maia de Souza *et al.* 2018). At the same time, studies dealing with life cycle thinking combined with urban metabolism (UM) assessment and/or input-output (IO) analysis methods (e.g. Pincetl *et al.* 2012; Goldstein *et al.* 2013; Beloin-Saint-Pierre *et al.* 2017; Petit-Boix *et al.* 2017; Sohn *et al.* 2018) confirm the findings of the present review, i.e. that both UM and IO based models can arguably benefit from the accommodation of bottom-up LCI technology knowledge, which considers micro-scale details, although this is at the expense of increased modelling complexity. Other attempts to use the complementary features of methods is hybridization of UM and LCA. While MFA-based approaches, such as UM, HHA, SS, measure material flows to/out of a city or system, which is useful for the quantification of the circularity potential, it lacks assessing the environmental impacts of these flows. Thus, hybridization with LCA fills up this gap and it was implemented in Chester *et al.* (2012); Goldstein *et al.* (2013).

In this regard, the present analysis has further confirmed that it is worth adopting the main assets of LCA in the context of macro-scale assessments, e.g. the standardization criteria of the LCA method, the representativeness, transparency and completeness of the LCI databases, the necessary flexibility to host different types of flows in LCA models, not only physical but also monetary flows, etc. However, the isolated use of LCA and its family of methods (such as S-LCA, LCC, etc.) will always generate biases and a lack of consideration of the many landscape features, cultural diversity, and socio-economic attributes that characterize the cities as complex and dynamic systems. Therefore, a more top-down approach shall be undertaken to coupling LCA with other tools. As already highlighted by some works (e.g. Onat *et al.* 2017; Marvuglia *et al.* 2018; Beaussier *et al.* 2019), when combined with LCA tools, such as system dynamics, agent-based modelling, etc., can allow to capture the multifaceted features of those systems, bringing to more comprehensive studies of the urban metabolism as a showcase to establish circular city models.

Additionally to the previously described assessment methodologies, a number of decision support tools has been used aiming to facilitate the NBS implementation in cities. Most of them focus on sustainable urban drainage, i.e. on integrating water and green infrastructure to achieve multiple benefits. To name a few, Urban BEATS (Bach *et al.* 2015) simulates the planning, design and implementation of water sensitive urban design infrastructure in urban environments. In addition the Adaptation Support Tool (Voskamp & Van de Ven 2015) facilitates the collaborative planning towards more resilient and attractive environment. E2STORMED is a comprehensive decision support tool that applies Multi-Criteria Analysis (Morales-Torres *et al.* 2016) and includes a catalogue of more than 20 types of drainage infrastructures. Radinja *et al.* (2019) have introduced a DSS that supports design and evaluation of blue-green infrastructure based on hydrology-hydraulic modelling.

SURVEY RESULTS AND DISCUSSION

This section presents the results of the survey as described under Project Survey Approach. It is important to underline the fact that most of the information extracted from the target projects is self-reported, while the projects come from various scientific fields, scale of enforcement or lines of financing. Therefore, the survey results provide the basis for a broader analysis.

Figure 3 shows the general information about the surveyed projects, while results that specifically focus on Policy and Regulations, Stakeholder Engagement and Awareness, and Tools and Methods are presented in the following sub-sections.

Regarding the different project types – shown in Figure 3(a) – around 70% of the projects are self-identified as RIA and IA, indicating that there is a considerable number of pilot projects that are actually implemented. The majority of the projects have low to medium Technology Readiness Levels (TRLs) indicating that the maturity of either the investigated topic (NBS and related applications)

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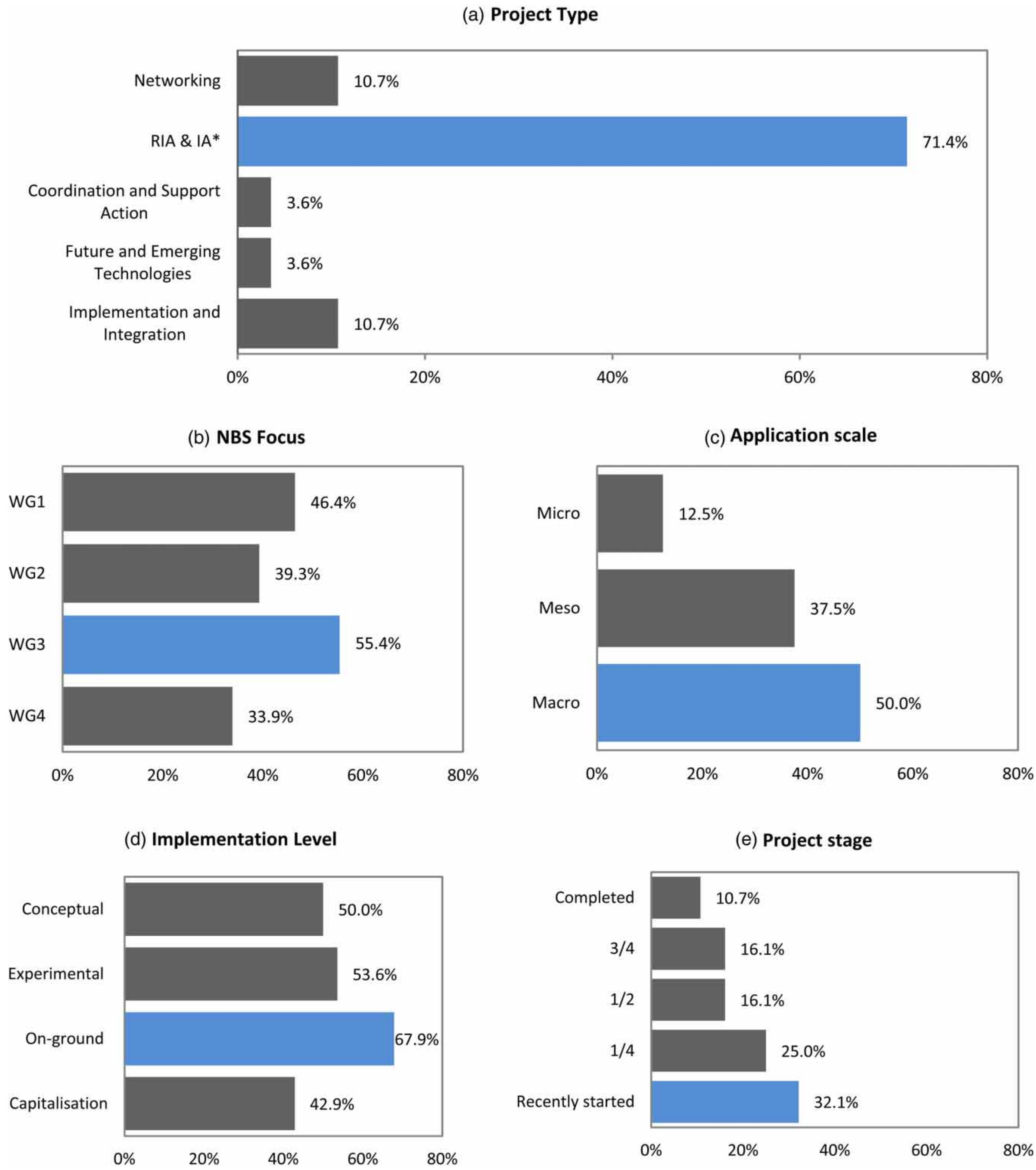

Figure 3 | Categorization of the selected projects. *RIA stands for Research and Innovation Action, IA stands for Innovation Action.

or the application of the method(s) still necessitates improvements and innovation. This may be explained by the fact that the concept of Circular Cities is quite recent, while the direct or indirect quantifiable, social/economical or ecological benefits captured by the implemented NBS projects are still quite unexplored (Marin & De Meulder 2018; Petit-Boix & Leipold 2018).

The second classification – related to the focus of NBS (Figure 3(b)) – results in an equal representation of all categories, which indicates that NBS for Circular Cities involve all sectors and disciplines in the urban development.

The results concerning the projects classification based on the scale of application (Figure 3(c)) indicate that half of the projects applied NBS at a city or regional scale, 37.5% of projects applied their

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technologies on a building or neighbourhood scale, while only 12.5% of the projects focused on the micro-scale.

The results regarding the implementation level (Figure 3(d)) demonstrate that different levels of implementation exist within the same project. Interestingly, a large number of projects (almost 68%) implemented their technologies on the ground (real engineering practice), which indicates the intention to provide empirical verification of the NBS concept.

Furthermore, the respondents stated the current project stage, i.e. level of completion ranging from just started to completed, at the time of the survey (Figure 3(e)). Out of the total of respondents, 10.7% of the projects are completed and 32.1% have started recently.

Policy and regulations

To understand the barriers or drivers that policies and regulations pose in practice, the following analysis was conducted. Among the 47 studied projects, 48% have considered European policies and regulations as the most important drivers or obligations for the project's implementation, followed by local regulations and governance (41%). Additionally, only 22% of the 47 projects undertook a policy/regulation review while, less than 10% have considered policy indicators for monitoring the success of their project.

Figure 4 shows the role of policy and regulation as drivers or barriers to NBS proliferation. Figure 4 further indicates that policy instruments, such as innovation, social, SDGs, and GI, are driving the changes while, more classical policies – linked to regulatory frameworks, such as water resources or environment – are considered as equally introducing drivers and barriers. It is worth noting that agriculture and biodiversity policies and regulations are perceived as more limiting rather than enabling the development of NBS. This can be due to NBS being developed in a close connection to the urban environment and its searches for sustainability or resilience, therefore NBS still need adjustments in spaces where the main objectives are different: biodiversity conservation or food production.

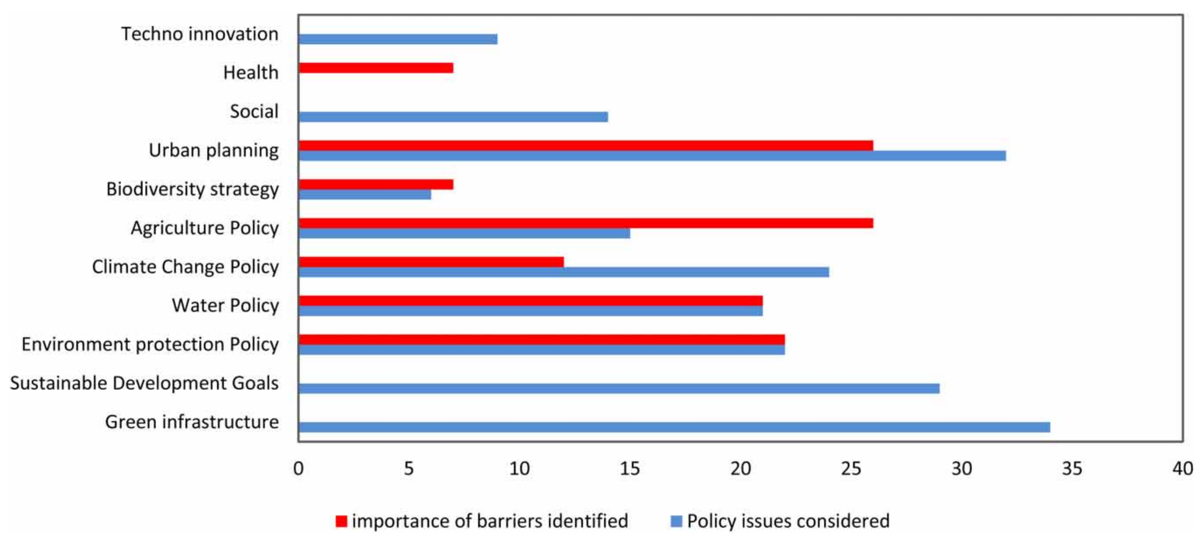

Figure 4 | Policies and regulations considered by projects and main barriers identified.

In addition to the survey conducted, Brink *et al.* (2016) identifies the lack of space in dense urban areas, environmental and building permits, and the possible conflict of interest with other ecosystem services (such as drinking water production), which can determine the appearance of ecosystem disservices in some situations (Schaubroeck 2018), as additional barriers to the NBS implementation.

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Policies can include the creation of supporting framework, requirement or incentive to foster the development, implementation and deployment of NBS in cities. Figure 5 presents the types of such supporting measures that the projects surveyed are considering as positively impacting their development. Most of these projects are science driven, so unsurprisingly research and innovation frameworks are considered first, followed by political commitment and ownership. A suitable environment for market exploitation associated with financial incentives (grants and reduced taxes) is expected to boost NBS deployment in cities. Additionally, a long-term perspective of local governments on funding is necessary in order to create stability, decrease uncertainty for activities and enable voluntary action for a sustainable transition.

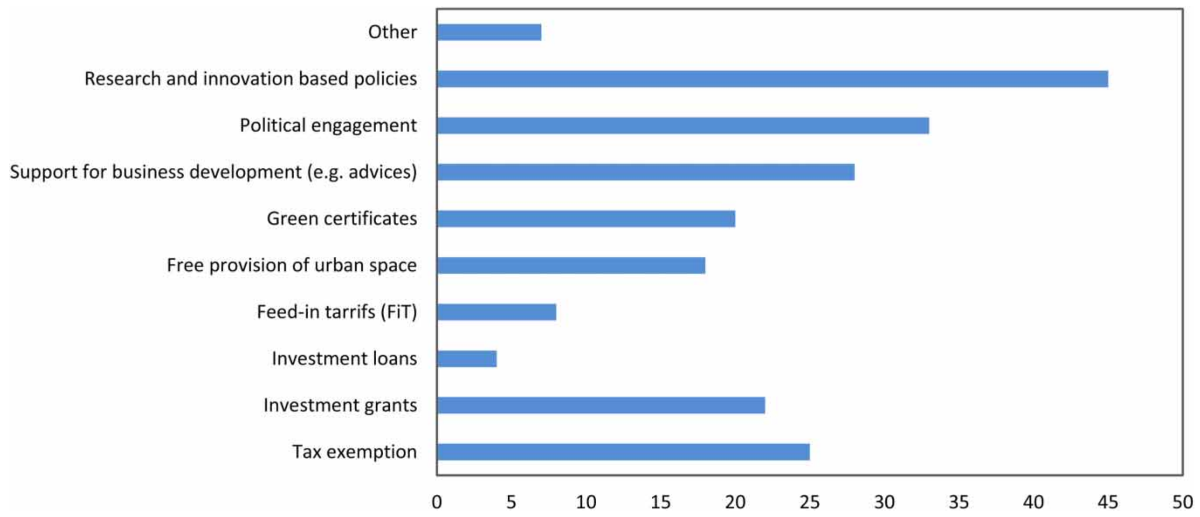

Figure 5 | Supporting measures considered by projects.

Stakeholder engagement and awareness

To understand the degree of stakeholder awareness and engagement in practice, the following analysis was conducted. Findings related to the types of stakeholders involved in the different projects are presented in Figure 6. In total 12 types of involved stakeholders were identified in the projects, with

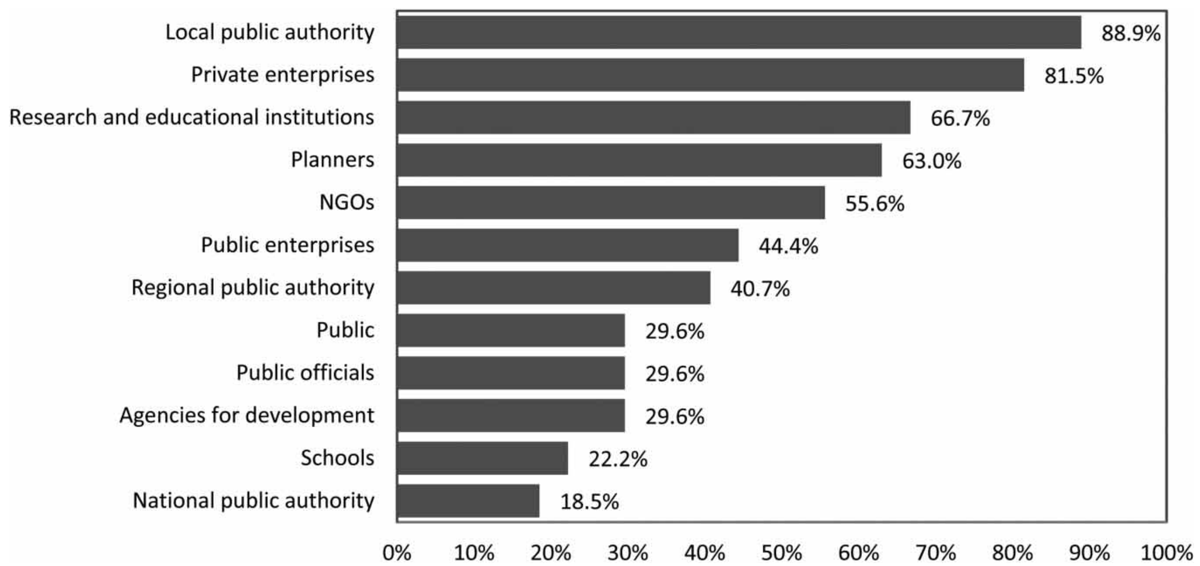

Figure 6 | Types of stakeholders involved in the projects.

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public authority bodies and private enterprises having the lion's share of participation while individual citizens are the least represented, confirming the lack of horizontal acceptance of NBS. NBS as a concept is multidimensional and its implementation requires collaboration amongst different policy areas, sectors and stakeholders (Van Ham & Klimmek 2017). More precisely, Figure 6 shows that the most represented type of stakeholder identified in the analysed projects was Local public authority (88.9%). Private enterprises hold the second place (81.5%), followed by Research and educational institutions (66.7%) and Planners (63%) while, on the place are National public authorities (18.5%).

Regarding the barriers for the implementation of project activities related to stakeholder awareness and engagement in the analysed projects (respondents could choose multiple answers), unsupportive legal frameworks (45.8%) and insufficient financial resources (45.8%) are identified as the main issues (Figure 7). These findings are further supported by literature, e.g. Brink *et al.* (2016) indicate that the lack of resources, know-how, tools, unsupportive legal frameworks are, among others, serious impediments to NBS implementation. Lack of time holds third place with 33.3%, followed by lack of basic knowledge about NBS (29.2%) and Lack of engagement plan (25%). Combination of the previously mentioned five barriers for stakeholder awareness and engagement is present in almost every project.

Figure 8 presents the most common participation tools and techniques that are used in the projects for stakeholder awareness raising and engagement on NBS. Among others, respondents identified Participatory workshops (63.6%), Internet (45.5%), Public meetings (45.5%), Printed information (e.g. brochures, leaflets, newsletters) (40.9%) and Regional focus groups events (27.3%) are the most common participation tools and techniques used for stakeholder awareness and engagement on NBS. Besides these five categories, there were also external events (e.g. fairs, promotions, exhibitions), telephone contact, newspaper and semi-structured interviews, represented with less than 25% in provided answers. Results from Figure 10 indicate a shift from 'traditional techniques and tools', such as telephone and printed media, to the increased use of social media and the internet. The fact that social media and internet are more popular probably also depends on the type of stakeholders that are commonly engaged in participatory events (youth and urbanized population), while an older population favours printed media. It is important to consider that a 'participation divide' (Hargittai & Walejko 2008) between elders and youth, urban and rural, and middle-high and low income affects such a result (Hargittai 2002; Paul & Stegbauer 2005; Sylvester & McGlynn 2010). Further research might be useful for future NBS implementation considering different groups of stakeholders.

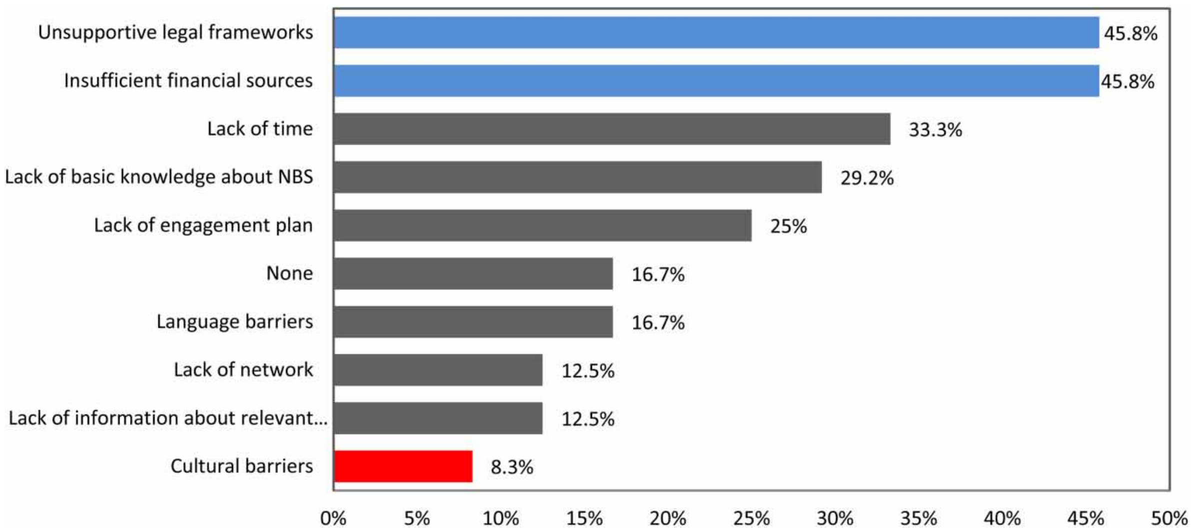

Figure 7 | Barriers to the implementation of project activities related to stakeholder awareness and engagement.

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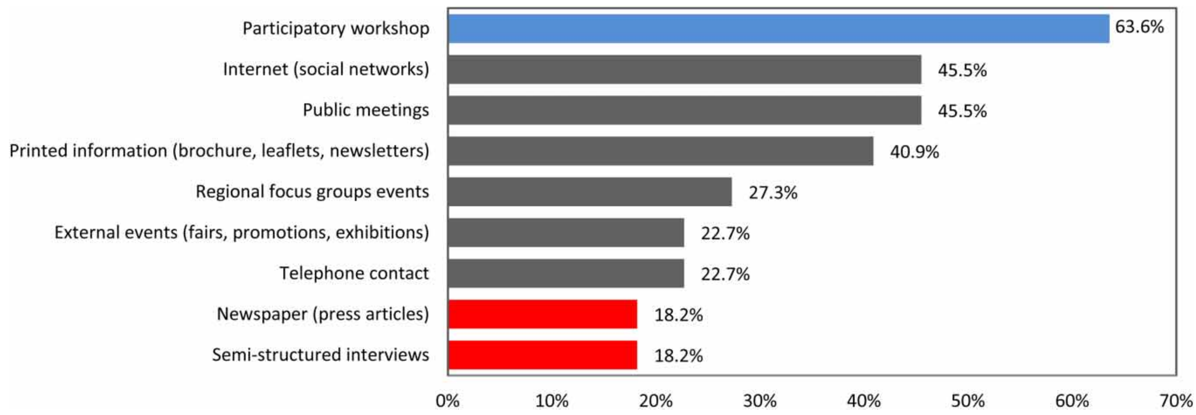

Figure 8 | Public participation tools and techniques used in the project for stakeholder awareness raising and engagement on NBS.

According to the International Association for Public Participation, there are five levels of stakeholder engagement, i.e. inform, consult, involve, collaborate and empower (International Association for Public Participation (IAP2) 2007). According to this categorization, the level of stakeholder engagement in the analysed projects was identified (Figure 9). It should be noted though that the results only represent the respondents' perception regarding the level of stakeholder engagement in their project.

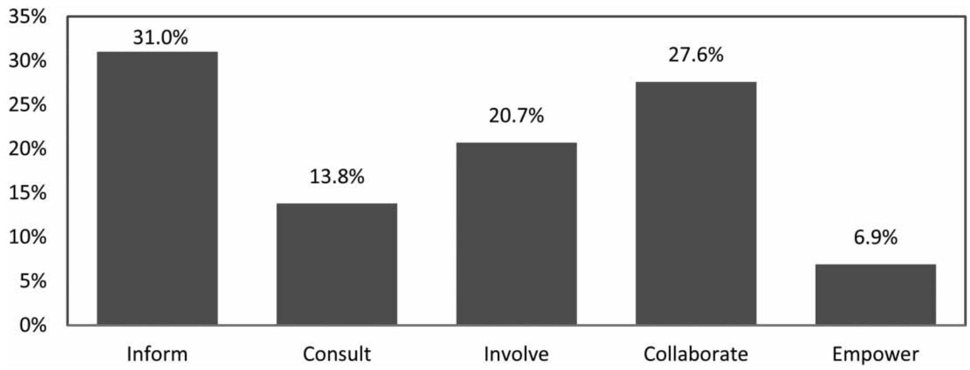

Figure 9 | Level of stakeholder engagement in the projects.

In the majority of the projects (31%), stakeholders were informed in order to understand the problem, alternatives, and opportunities related to NBS. In 13.8% of the projects, stakeholders had a consulting role in order to provide feedback on the analysis, the alternatives and/or the decisions related to NBS. 20.7% of the respondents involved stakeholders in their projects to work directly with them throughout the process in order to ensure that stakeholders' concerns and aspirations about NBS are consistently understood and considered. In 27.6% of the projects, collaborative methods (e.g. collaboration for the development of alternatives, identification of preferred solutions) – which help mobilize stakeholders and build capacity to deliver projects (Healey 1998) – are deployed in stakeholder engagement. Regarding the highest level of stakeholder engagement, only 6.9% of the respondents empowered stakeholders in their project to make a final decision.

Results of cross-tabulation analysis between the different types of the projects and level of stakeholder engagement are presented in Figure 10. The results of this analysis reveal that Research and Innovation projects engage the highest number of stakeholders and among them, in 20.7% of the R&I projects stakeholders were informed, in 10.3% they were consulted, in 10.3% they were involved, in 13.8% they collaborated and in 6.9% stakeholders were empowered.

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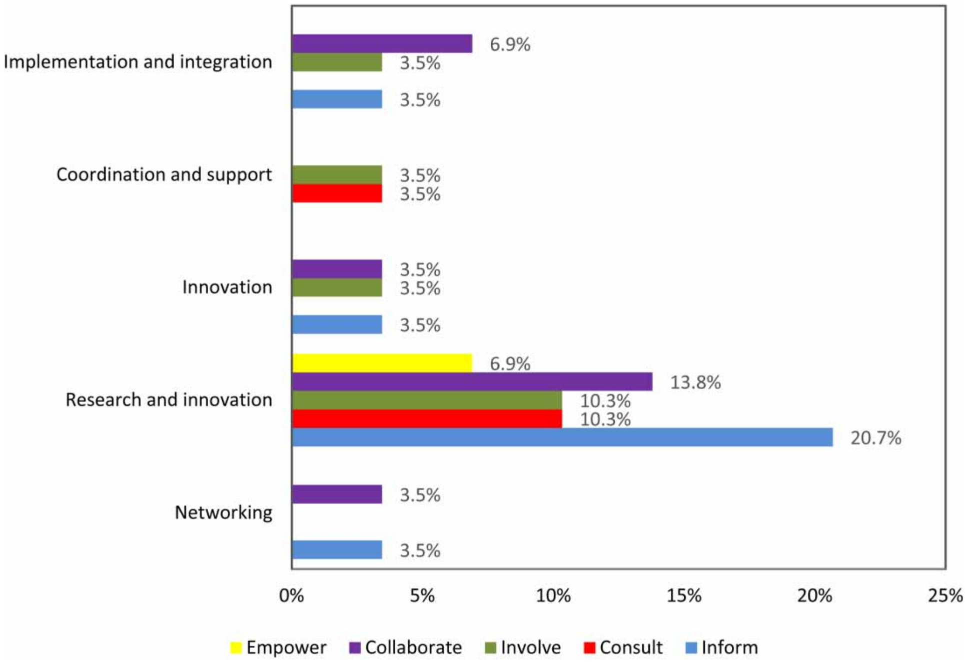

Figure 10 | Cross-tabulation between the type of the project and level of engagement.

An additional cross-tabulation analysis between the level of project's implementation and the level of stakeholder engagement (Figure 11) reveals that projects implemented at the macro level (city, regional) engaged the highest number of stakeholders out of which, 20.69% were informed, 6.9% were consulted, 10.34% of the stakeholders were involved, 10.34% were collaborated and 3.45% were empowered.

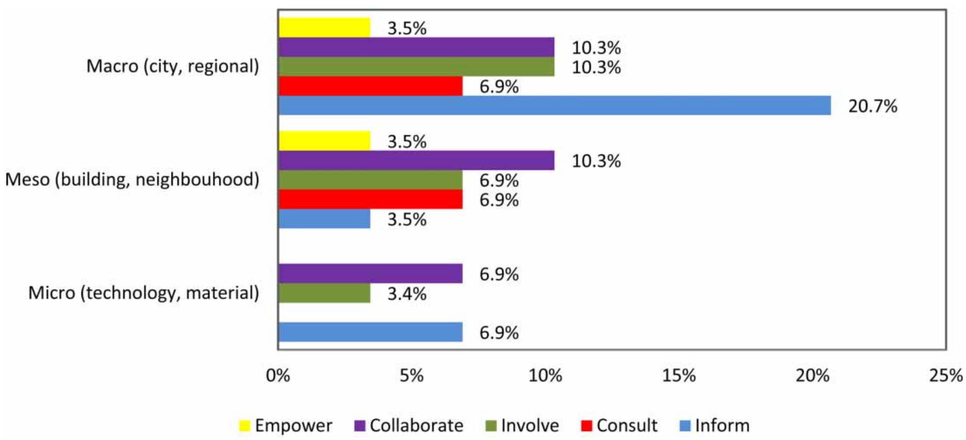

Figure 11 | Cross-tabulation between application scale of the project and level of engagement.

Tools and methods

To understand which assessment methodologies are mostly employed in practice, the following analysis was conducted. The assessment methodologies that are applied in the targeted projects are presented in Figure 12, indicating that a wide variety of assessment methodologies is used. In general, it is worth noting that the assessment of NBS is mostly focused on the environmental and economic aspects, while the social aspect of the NBS implementation is underestimated (i.e. 12.5% of the

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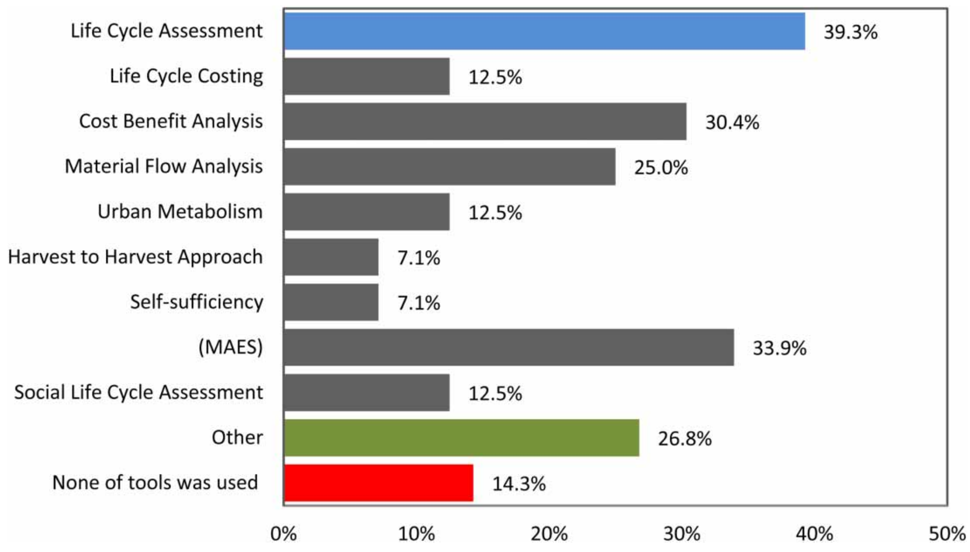

Figure 12 | Methods used for the assessment of the applied solutions.

projects conducted S-LCA) in the projects. More precisely, most projects apply one of the following assessment methodologies: (i) LCA (39.3%), a well-established method for sustainability assessment; (ii) Cost Benefit Analysis (30.4%), in order to prove the cost effectiveness of the implemented solutions; and (iii) Mapping and Assessment of the Ecosystem Services (MAES) (33.9%), as the enhancement of the ecosystem services is the cornerstone of NBS. MFA is also considerably applied in the projects (25%), which can be explained by the fact that it is another well-established method to measure the circularity of systems (EC 2015b; Linder *et al.* 2017). Consequently, it can be argued that in practice (i.e. implementation of a project) well-established methods are more favourable compared to other newly developed methods (e.g. HHA or SS) or to methods that are not directly linked to NBS or circularity assessment (i.e. Urban Metabolism).

Regarding the application scale of the projects (Figure 3(c)), several projects were carried out on-ground. As those projects might be very useful for the transferability of the concepts of NBS for Circular Cities, a further analysis of the results of on-ground projects regarding their application scale was carried out. Figure 13 shows that 52.6% of these on-ground projects have been applied on a macro-scale, and 39.5% of them have been applied on a meso-scale.

The methodologies that have been used in on-ground projects to assess the effectiveness of the applied technologies with regard to their application scale are summarized in Figure 14 – (left) assessment methodologies applied on a meso-scale, and (right) assessment methodologies that have been applied on a macro-scale.

Meso-scale projects (Figure 14-left) mostly use Life Cycle Assessment (LCA) (46.7%) to assess the sustainability of their proposed technologies, while 40% of these projects additionally use material flow analysis (MFA). It is evident that the economic aspect is underestimated among these projects, since 20% use Cost Benefit Analysis (CBA) and only 6.7% use Life Cycle Costing (LCC). In contrast,

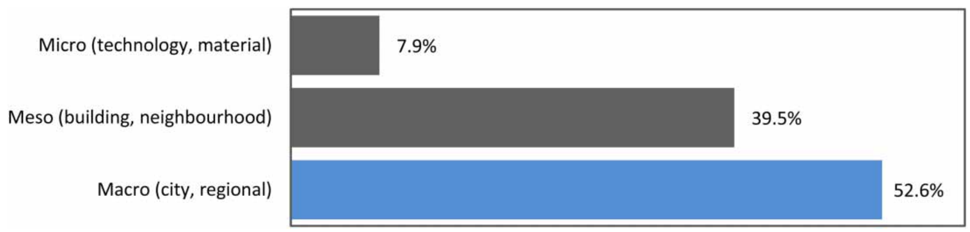

Figure 13 | Distribution of on-ground projects regarding their application scale.

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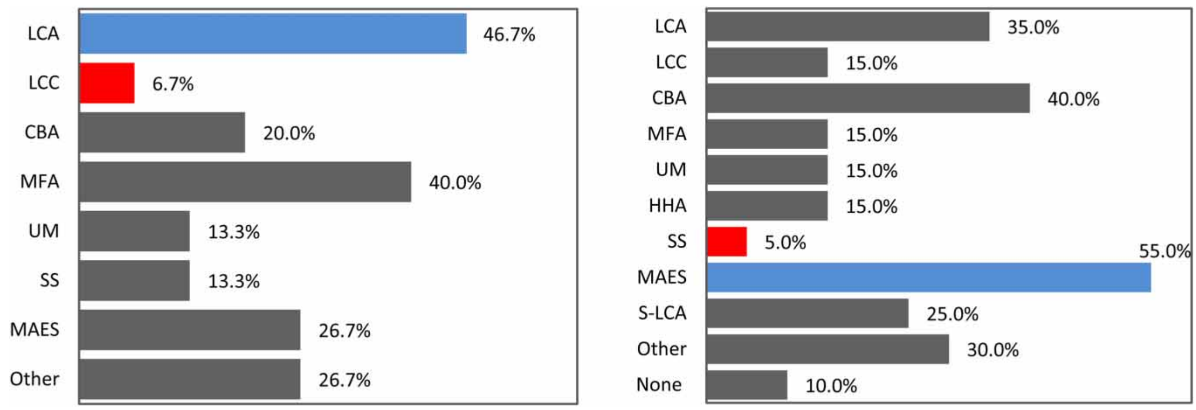

Figure 14 | Assessment methods for on-ground projects on meso- (left) and macro-scale (right).

this trend changes significantly when on-ground projects applied on a macro-scale. In this case (Figure 14-right), the most widely applied methodology is the Mapping and Assessment of Ecosystem Services (MAES) and only 35% of the projects use LCA. Ecosystem Services are implemented in larger scales (e.g. catchment-scale, watershed-scale, etc.), while in a smaller scale (e.g. neighbourhood scale) only the relative changes in ecosystem services can be assessed. LCA on the other hand, is mostly used to assess the sustainability of specific systems (meso-scale), e.g. wastewater treatment plants. Although LCA can be applied at larger scales as well, there are only a few studies that have performed this type of analysis. For example the study of Lane *et al.* (2015) includes the assessment of the environmental impact of a broad range of technologies at the 'whole-of-system' level – urban water system. Therefore, the change in the preference of the assessment methodologies would be better explained if the assessment scale is also known. In case the assessment scale coincides with the application scale of the technologies, then the reason behind this change in preference is clear. Moreover, on-ground projects at macro-scale are more focused on the economic aspect of their technologies, as 40% of these projects use CBA.

Some useful ICT tools were used and reported in these projects too. They can be grouped as (i) data or databases (including GIS for 3D visualization, weather gridded, energy carbon footprint, data mining sensors, cloud-based geo-referenced system for storing and communicating the acquired water quality information, or websites containing data for mapping of pilot areas), (ii) models (for temporary housing, climate adaptation, water management strategies or for gaming in some apps), (iii) monitoring and control systems (for online greenhouse gases emission in wastewater treatment plants based on wireless sensor networks, for ecosystem services adapted to urban areas, for real-time flood mitigation, for waterloops or for automation and process control in general), (iv) Decision Support Systems to select among alternatives or to identify potential pollutant sources and predict the effectiveness of mitigation measures. Commercial software (e.g. simulistics, UnicaLids or MATLAB, etc.) and platforms with open-source information (e.g. OPPLA, thinknature, Tygron, ICT governance, or for e-learning courses like edXMOOCs) have also been reported for the implementation of NBS.

CONCLUSIONS

Adoption and implementation of NBS in Circular Cities is circular itself and require four main steps, i.e., planning, design, assessment, and communication. Policies and regulations, stakeholder engagement and awareness, and tools and methods assessing the socio-economic and environmental impacts of the solutions are integral parts of this circular process.

The state-of-the-art analysis performed in the present paper, revealed that limited research has been conducted on 'policies, regulations and governance' for deploying NBS to move towards Circular

Cities; a deeper analysis is still required. Circularity initiatives and NBS imply risks and unknowns, compared to classical solutions, and are not compatible with current rules and regulations. The survey results confirmed these findings revealing that many of the current policies and regulations are almost equally perceived as both limiting and enabling the development of NBS. Experimentation zones where these prevention principles and regulations are not (fully) applicable for specific projects could be a solution. The EU is moving in that direction with the 'innovation deals' initiative, in particular one launched on treated wastewater reuse.

The literature revealed that public awareness and social acceptance are key issues related to the success of NBS for Circular Cities, as they can reduce barriers to NBS adoption and diffusion on a wider scale of application. Respectively, the projects' survey demonstrated that the level of stakeholder engagement is very important in order to achieve accepted outcomes, as well as for successful project delivery. However, unsupportive legal frameworks and insufficient financial sources were identified as the main barriers related to stakeholder awareness and engagement. The projects' survey demonstrated that participatory workshops, social media and public meetings are the most common public participation tools and techniques used in the projects for raising stakeholder awareness and engagement. Therefore, this study implies that such tools should be further investigated with regards to each one of the four steps for NBS application so that their utilization is more productive.

The analysis of existing tools advocates more quantitative upscaling of NBS technologies, although research and innovation in this field seems to be still in their infancy. An extensive diversity of tools and methods assessing the impacts of NBS was identified in the literature, as well as in the selected projects, which complicates the comparability and measurability of such projects, as well as their transferability on a wider scale. However, based on the results from the survey it was found that the assessment methods that are mostly used are the ones that are well-established, such as LCA, CBA, MFA, while recently developed methodologies (e.g. HHA) are not in favour even though they may be very prominent for the assessment of NBS for creating Circular Cities. Interestingly, it was found that the decision on the employed methodologies is related to the application scale of the project. A further and more focused analysis on the nature of tools applied for every step of the application of NBS, i.e., planning (routinely considering NBS, integrate triple benefits targets: economy, community and environment, build new partnerships to bring new resources and skills), design (using advanced tools and guidelines integrating NBS), assessment (learning new lessons for closing the knowledge gap, and communication (engaging policy makers, building capacities), would lead to a more straightforward methodology. More specifically, the development of a widely accepted methodology or framework for assessing NBS for Circular Cities would provide the guidelines regarding the hybridization of the different methods and it would systematize the evaluation of the effectiveness of NBS for creating Circular Cities.

Improving knowledge on the impact of NBS is moreover, necessary for decision makers to prepare a transition process to circular systems. The EU is leading a wide range of developments in particular with enabling environments (e.g. policies, innovation funds), while at the global level, IUCN (IUCN 2012; Cohen-Schacham *et al.* 2016) and the World Bank (WB 2019) are advocating for NBS to be more integrated into new initiatives, in particular infrastructure projects.

Continuous monitoring that would be enabled through the use of ICT tools and evaluation of the implementation of NBS for circular cities will support the development of a solid knowledge base for more suitable policies and regulations.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available at https://dx.doi.org/10.2166/bgs.2020.929.

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